MANAGEMENT OF LARGE INTERDISCIPLINARY TEAM SCIENCE PROJECTS:

A MULTI-METHODS APPROACH TO EXAMINING COMPETENCIES

By

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Abstract

Over the past fifty years, the world has experienced a significant increase in the scale and complexity of scientific research that is focused on society's most important issues. This type of research requires a team approach from people with diverse skill sets working together across multiple disciplines, and that trend is reflected in a significant rise in collaborative research. "Team science" is the focus of research efforts intent on better understanding the challenges and maximizing the effectiveness of collaborative research. Projects that involve large teams of scientists require a thoughtful and planned approach to leadership and management in order to achieve the stated goals and outcomes. The science community has recognized that in order to run effective team science projects, people must identify the knowledge, skills, attitudes, values and beliefs that define the competency set for large-scale team science leadership and management. This study used a mixed-methods approach to obtain both quantitative and qualitative data through group concept mapping to develop a concept map of the competencies required to lead and manage large, interdisciplinary team science programs. These results were then used as a lens to examine the competencies identified through the content analysis of hiring documents for positions related to a broad spectrum of team science efforts. Expert team science managers defined a list of five critical competencies: project management, shared leadership, personal competence, social competence and communication. Analysis revealed that hiring practices do not identify these skill sets in position descriptions and announcements, typically focusing on project management and communication and neglecting the remaining three competencies. In order to hire people capable of managing large science teams, hiring practices, training programs and career tracks must be developed and align with these core competencies.

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Chapter 1 Introduction

Over the past fifty years, the world has experienced a significant increase in the scale and complexity of scientific research that is focused on society's biggest challenges including curing cancer, developing sustainable energy options, and eliminating poverty. Solutions to these highly complex issues require many people working together across multiple disciplines, and that trend is reflected in a significant rise in collaborative research. These collaborative projects have come to be referred to as "team science" and are the focus of significant research efforts intent on better understanding the challenges and maximizing the effectiveness of collaborative research. While science teams may benefit from larger pools of collective resources in terms of personnel and equipment when compared with single-investigator projects, they also possess challenges in terms of communication, coordination and management that are inherent in their large scale. Projects that involve large teams or teams of teams of scientists require a thoughtful and planned approach to management in order to achieve the stated goals and outcomes. The science community has begun to recognize that in order to run effective team science projects, people must identify the knowledge, skills, attitudes and values that define the competency set for large-scale team science leadership and management. This study used a mixed-methods approach to collect both quantitative and qualitative data through group concept mapping (GCM) to develop a concept map of the competencies required to lead and manage large, interdisciplinary team science programs. These results were then used as a lens to examine the competencies identified through the content analysis of hiring documents for positions related to team science efforts across the country. The following sections of the introduction provide the context for this study by laying a foundation for and identifying the challenges of team science, clarifying terms related to the field, and describing the methods and participants chosen for this research.

The Evolution of Team Science

Science was once seen as a solitary effort with great minds making fantastic discoveries. With the increased level of complexity of today's problems, scientists are more likely to work in teams and provide expert disciplinary knowledge in an effort to support the larger project. This ongoing shift in research from single- to multi-investigator research efforts has taken place over the past half century in science-based areas of manufacturing, biomedicine and computer technology and large-scale projects such as the Human Genome Project. In 2007, a group of researchers from Northwestern University published their findings on a study of almost 20 million research articles from the fields of science and engineering, social science, arts and humanities and over 2 million patent records from the National Bureau of Economic Research to conclude that team work was increasing fastest in the life and physical sciences but was also increasing, albeit at a slower rate, in the social sciences (Wuchty, Jones, & Uzzi, 2007). The authors presented findings that showed that in 1960, 50 percent of publications in science and engineering listed at least two authors, and by the year 2000 that number had grown to 80 percent. A recent study by the Committee of the Science of Team Science found that in 2013, 90 percent of these same types of publications had multiple authors (National Research Council, 2015).

While the number of multi-investigator teams has clearly increased, Wuchty et al. (2007) also found that the size of teams increased over this time period. In 1960, science and engineering publications listed an average of 2 authors per paper, and by 2000 that number had increased to 3.5 authors per paper. Research figures for social science research publications showed smaller but similar effects between 1960 and 2000 with the percentage of multi-author papers growing from an average of 20 to 50 percent and the average team size doubling from just over 1 to slightly more than 2 people per publication. A subsequent study by the same authors looking at over 4 million papers published over three decades showed a shift in knowledge production from single university to multi-university efforts (Jones & Wuchty, 2008) In addition, the authors concluded that there was an increase in publications by authors from multiple institutions and that team research was increasingly crossing geographic and institutional boundaries. However, as this dissertation will address in subsequent sections, there also appeared to be a bothersome trend that fewer institutions were contributing to the highest impact research. Specifically, as Jones, Wuchty and Uzzi (2008) state, "Despite the rising frequency of research that crosses university boundaries, the intensification of social stratification in multi-university collaborations suggests a concentration of the production of scientific knowledge in fewer rather than more centers of high-impact science." These foundational studies illuminated the fact that the majority of research had become a collaborative activity by the year 2000, that teams dominated the publication outputs, and that fewer institutions were involved with high-impact research.

This clear identification that teams were becoming more prevalent in the scientific enterprise resulted in an increase in the study of teams to understand their unique challenges and to increase the effectiveness of team research endeavors. The First Annual International Science of Team Science (SciTS) Conference was held in Chicago, IL April 22-24, 2010 with the goal of enhancing the understanding of team science. This event brought together 200 participants including leaders from a wide range of academic arenas such as translational research, evaluation, communication, social sciences, complex systems, technology and management and marked the first international forum dedicated to the emerging field of the science of team science. Keynote speaker, Dr. William Trochim from Cornell University, presented findings of an empirical exercise undertaken in preparation for the conference. Conference participants and other experts were invited to participate in a Group Concept Mapping (GCM) exercise to identify a comprehensive set of ideas in SciTS that would help guide the future of scientific inquiry in this nascent field.

The conceptual map (Figure 1) derived from participant input helped to frame the direction and focus of SciTS research and provide a common visual framework for people who were participating in and thinking about team science. Three main concepts emerged from the group concept mapping exercise (Falk-Krzesinski et al., 2010):

1. Meta issues – measurement and evaluation of team science
2. The team – disciplinary dynamics and team science; nuts and bolts (structure and content for teams, and characteristics and dynamics of teams)
3. Support – institutional support and professional development for teams, and management and organization for teams

Other topics included collaborative dynamics, network perspectives of teams, strategies for facilitating team science, emerging directions for the fields, and the praxis of team science. This meeting set the stage for subsequent annual meetings and provided a conceptual framework to guide research endeavors.

Over the past decade since the foundational research of Wuchty et al. (2007), hundreds of papers have been written on a wide variety of topics pertaining to team science. These efforts

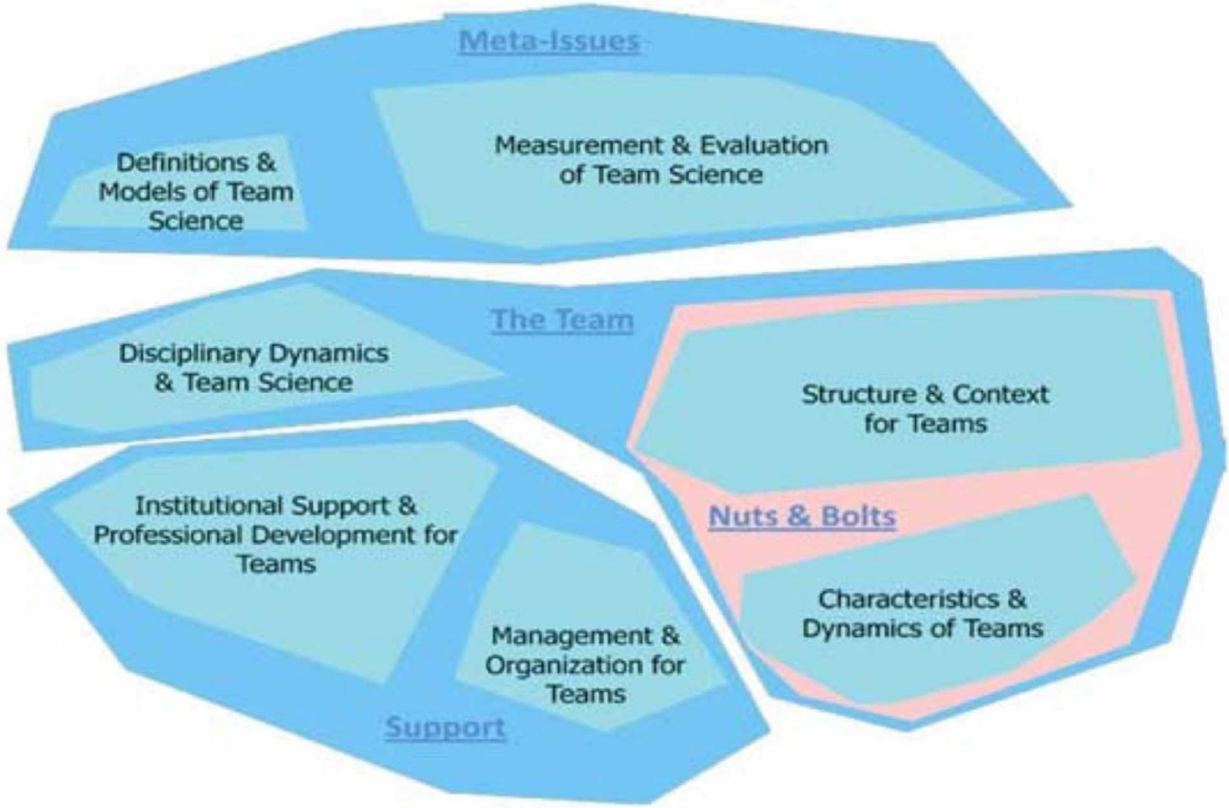


Figure 1. The conceptual map derived from the 2010 Science of Team Science meeting that summarizes the clusters of topics that are important factors in a research agenda for the science of team science (Falk-Krzesinski et al., 2010).

reflect a significant federal research budget that supports collaborative investigations into the complex societal problems that our planet faces today. To provide guidance in addressing these issues and identify the challenges and opportunities for team science, the National Science Foundation requested that the National Research Council (NRC) conduct a consensus study. The charge to the group was to “conduct a consensus study on the science of team science to recommend opportunities to enhance the effectiveness of collaborative research in science teams, research centers, and institutes. The committee will consider factors such as team dynamics, team management, and institutional structures and policies that effect large and small science teams." (National Research Council, 2015, p. 3). In the end, the committee identified seven key features that create challenges for team science that are not apparent in single-investigator research projects. If the current trend continues and much of our future effort is driven by team science, understanding and addressing these challenges will increase the chance that future scientific endeavors are successful.

Specific Challenges of Team Science

The NAS study identified specific features based on practitioner evidence, expert judgment and research findings that create challenges for team science. The first of these challenges is a high diversity of membership. Diversity within a science team may be seen in discipline, gender, geography, culture, role, and age. Diversity in membership can be beneficial in addressing issues that are important to different groups but can also impact the team's effectiveness in decision-making and conflict management. Cummings, Kiesler, Zadeh and Balakrishnan (2013) found that while diversity has positive impacts on interdisciplinary and transdisciplinary research outcomes, high diversity can weaken group identification. In addition, communication can be challenging with team members from different disciplines who are accustomed to speaking in jargon or technical language and who possess different attitudes toward knowledge development and ways of knowing (Knorr-Cetina, 1999).

The second challenge concerns the ways in which teams integrate knowledge. While teams benefit from the collaboration of people from different disciplines to address shared research questions, the process of integration can be difficult, especially when teams are examining interdisciplinary topics that also require stakeholder engagement. Not all participants will feel comfortable stepping out into a new culture, location or set of approaches to a scientific problem (Klein, 2010), and leaders must be aware of these situations to help guide the process. Interdisciplinary teams need to find a way to integrate knowledge even though people on the team may be concerned about their disciplinary identity (Salazar, Lant, Fiore, & Salas, 2012) or face institutional systems that do not acknowledge or promote this type of work (Fiore, 2008).

Challenge three focuses on the trend mentioned earlier of increasing team size (Wuchty et al., 2007). The NAS study found that between 1990 and 2000 publications were most frequently written by pairs and trios of authors, but that number has increased to 6 to 10 authors since 2000. In 2013, 95 percent of all papers listed 10 or fewer authors, 5 percent listed 11 to 100 authors and 1 percent listed more than 100. Again, large numbers can be beneficial to knowledge capacity. However, large team size can bring a significant challenge to leaders trying to promote trust among members, manage conflict and develop effective and efficient communication plans (Stokols, Hall, Taylor, & Moser, 2008). Research on the optimal size of science teams found that large groups required more time to reach high productivity and that productivity decreased as team size increased (Cummings et al., 2013).

Goal misalignment, the fourth challenge, is prevalent in large teams or teams of teams, such as those working in NSF Science and Technology Centers (STC's), the NSF Experimental Program to Stimulate Competitive Research (EPSCoR), national research laboratories and other large-scale projects that are composed of multiple teams of teams who may have competing goals. In fact, goals may even vary across the different scales with smaller team goals being misaligned with larger scale goals (Hall et al., 2012). New research on multi-team systems may provide a way to think about how best to align smaller teams within a larger system (Asencio, Carter, DeChurch, Zaccaro, & Fiore, 2012) in order to keep the entire organization moving forward.

The fifth challenge is concerned with team boundaries and permeability and the shift in membership due to changing landscapes and needs over time. Personnel within teams are constantly changing as people seek new positions, students enter and graduate, and needed expertise is gained and lost. Scientists tend to have autonomy over the projects that they join and may be part of several teams at once. Large projects, however, may require a significant amount of sustained effort from research teams. Cummings and Haas (2012) reported that teams whose members spent a larger percentage of time working with the team were more successful than those who spent less time working with the team.

Challenge six, geographic dispersion, is a common problem for teams today as many teams require expertise that cannot be found locally. Multi-university collaborations are much more common today (Jones et al., 2008) than they were just a few decades ago in the 1980's. Technological advances allow scientists to remain engaged across time and space, and many work on virtual platforms even when team members are located on the same campus or even in the same building. Wide geographic diversity brings with it challenges such as mismatched time zones, large travel distances for face-to-face meetings and institutional variations in incentives and duties.

High task interdependence and the necessity of relying on others to succeed is the seventh challenge and is a key feature of any team that has shared tasks (Fiore, 2008). Fiore (2008) has done a significant amount of work on interdisciplinary and transdisciplinary teams to show that these groups can become highly interdependent, especially compared to teams that do not require a high level of knowledge sharing. However, the necessity to share information and address problems collaboratively can increase the chance of conflict, and having to do this across large geographic distances or virtual platforms can add another level of complexity.

NSF EPSCoR: Facing the Challenges of Team Science Management

The challenges listed above pose no small threat to large, interdisciplinary team science programs. The need to address these challenges is critical to the future of inter- and trans-disciplinary team science. Understanding how best to maximize these large-scale opportunities will not only increase the chance of successful team science outcomes but also help funding agencies define and promote the best possible research opportunities. Science team leaders and managers are the point people responsible for successfully navigating these challenges and helping individual team members participate in successful projects. However, while these roles are of critical importance to successful outcomes, "currently, most leaders of science teams and larger groups are appointed to their positions based solely on scientific expertise and lack formal leadership training" (National Research Council, 2015, p. 9). In fact, one of the current questions that team science researchers are addressing in 2017 is how different management approaches and leadership styles influence the effectiveness of team science. The NAS states "The first step toward increased effectiveness is to gain understanding of the factors that facilitate or hinder team science and how those factors can be leveraged to improve the management, administration and funding of team science." (National Research Council, 2015, p. 42).

The NSF Experimental Program to Stimulate Competitive Research (EPSCoR) has been funding large, interdisciplinary state-based team science programs for several decades (Figure 2).

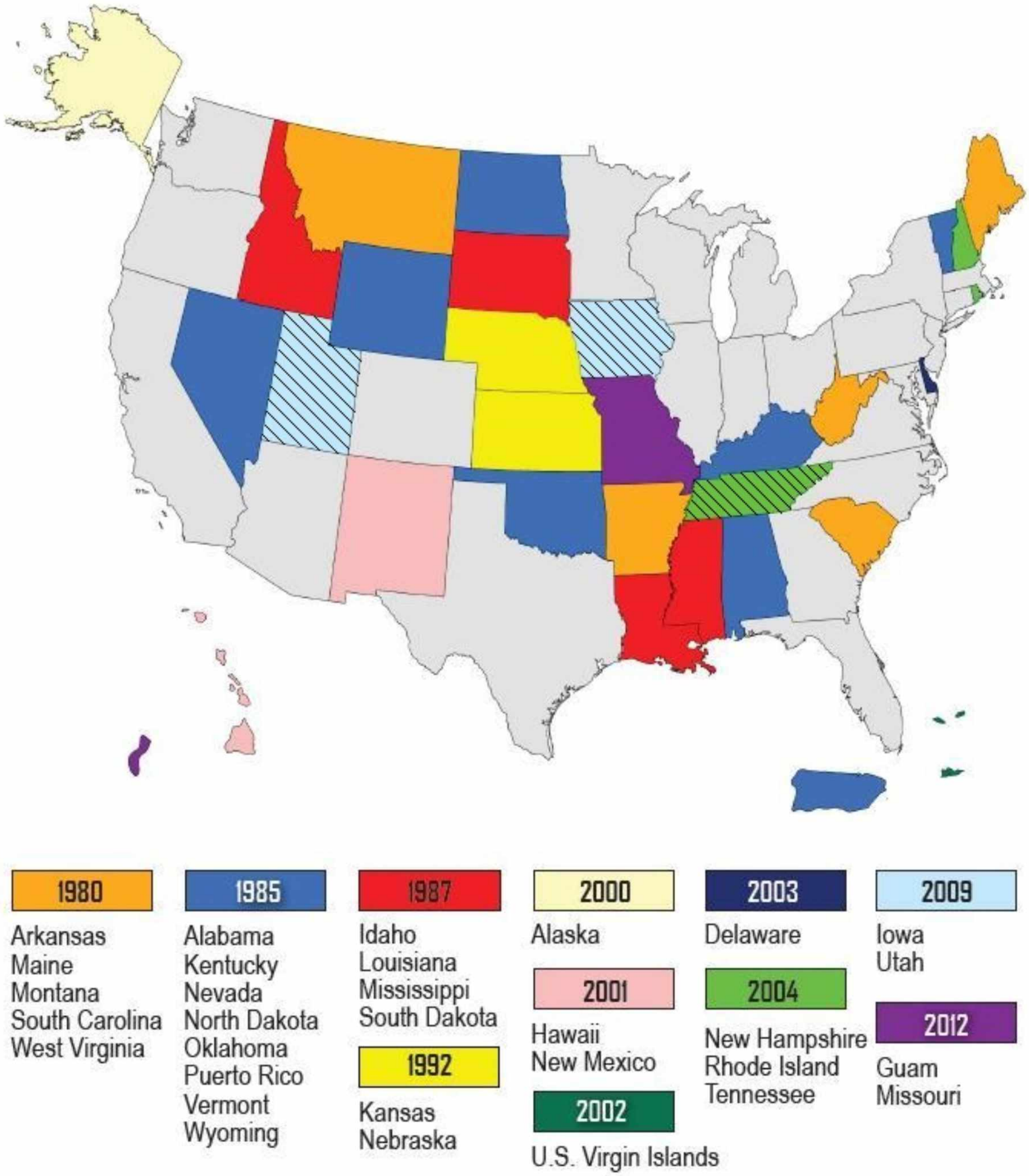


Figure 2. Map of the EPSCoR states that notes the first year of eligibility in the program. The states identified with stripes graduated from the program by surpassing the minimum funding levels as required by eligibility rules ("EPSCoR Jurisdictions," 2017).

The leaders and managers of these programs who have met semi-annually over the lifetime of the program hold a wealth of knowledge and expertise in team science management and leadership techniques and have served as the expert participants for this study. As the Associate Project Director of Alaska EPSCoR, the author participates in these group meetings and recognizes the wealth of knowledge in the collective body of this cohort. As a result of this expertise, the NSF EPSCoR leadership group was identified as the best group to provide input into the group concept mapping exercise for this research. The following section provides a brief overview of NSF EPSCoR and highlights the scope and diversity of this national program.

The NSF established EPSCoR in 1979 due to a concern in Congress that federal research and development grants were unevenly distributed across the United States and territories. After World War II, research centers that received a majority of NSF funding tended to receive even more support over time, concentrating the funding in a small number of highly competitive states. This trend ignored the fact that dramatic growth was taking place in regional educational and research institutions; the country was not benefitting from the diversity in talent and expertise spread across the country. Leadership at NSF created EPSCoR to help institutions build infrastructure, research capabilities, and training and human resource capacities to enable them to compete more successfully for open federal R&D funding awards. “Eligibility for NSF EPSCoR funding is limited to states (including some territories and the District of Columbia) that received 0.75% or less of total NSF research and related activities (RRA) funds over the most recent three-year period. EPSCoR awards are made through merit-based proposal reviews” (“Established Program to Stimulate Competitive Research (EPSCoR): Background and Selected Issues,” n.d.). In 2017, 25 states and three territories were eligible for EPSCoR funding. In addition to NSF, the National Institutes of Health (NIH), the National Aeronautics and Space Administration (NASA), the Environmental Protection Agency (EPA), and the Departments of Defense, Energy and

Agriculture currently have or have had EPSCoR-like programs, and while some have changed or even disappeared over time, NSF EPSCoR has remained strong and grown since its inception in 1980.

The complex nature of these state-based team research programs requires significant and professional management and leadership to ensure successful deliverables as stated in the cooperative agreement. Each state's NSF EPSCoR research team would be identified as highly complex in all seven categories identified by the NAS study. By their very definition, the state programs are teams of teams, one of the most complex endeavors to manage. Most of these programs are inter- or trans-disciplinary in nature and rely on a high level of task interdependence and shared disciplinary knowledge to achieve their scientific goals. Boundaries can be relatively porous in these programs as students and research faculty move in and out of institutions and with them the corresponding expertise needed to do the science. Goal misalignment is commonplace as most EPSCoR researchers work on multiple projects within university institutions with complex bureaucracies. EPCSoR projects are distributed across each state's territory, display a richness of diversity that reflects the people of the state, and typically involve numerous scientific disciplines in order to address a state's unique, place-based research needs. The high level of complexity of NSF EPSCoR state-based programs requires a corresponding high level of management experience to ensure success.

NSF EPSCoR manages several types of funding mechanisms, the largest of which is the Research Infrastructure Improvement (RII) Track-1 award. Over the past decade, the NSF EPSCoR RII Track-1 awards have increased in amount and duration from $9 million over 3 years to $20 million over 5 years. Jurisdictions that were successful in securing this funding were required to construct leadership and management practices to ensure the programs had the necessary oversight and leadership to keep the project running smoothly, reach the stated goals, and provide the final deliverables to NSF. This increase in funding, the related increase in the number of people involved with each state-based program, and the level of complex activity across the research teams provided an interesting parallel to the increase in science team size and co-authorship numbers across the country and made EPSCoR teams an ideal research focus for understanding the shifting challenges of large team science leadership and management.

States that were successful in their proposal submissions were awarded $20 million over 5 years to increase the research capacity within the state. Each program engaged dozens of researchers, students and stakeholder partners. Each of the 28 EPSCoR jurisdictions identified several primary points of contact: a principal investigator (PI) ultimately responsible for the overall leadership of the project, a project administrator (PA) typically in charge of the day-to-day administration of the award, and an education, outreach and diversity (EOD) manager responsible for overseeing the broader impact mission. While NSF required the positions of PI and PA, they did not define the specific details of the positions, and each state defined the responsibilities in a manner that worked best according to their local needs. Leaders of these 28 programs spread across the United States provided a rich and diverse set of research participants with a history of leading and managing large scientific programs in a broad range of thematic areas ranging from nanotechnology and energy to water resources and social-ecological systems (Table 1).

Table 1. Summary of NSF EPSCoR jurisdiction research foci in 2017.

STATE	RESEARCH FOCUS
Alabama	Nano/Bio Science and Sensors
Alaska	Social-ecological systems
Arkansas	Novel, multifunctional, and tunable surfaces with engineered properties
Delaware	Water and energy sustainability
Guam	Coral reefs and climate change
Hawaii	HI aquifers, water flow and transport processes
Idaho	Managing landscapes for ecosystem services
Kansas	Climate change and energy: basic science, impacts and mitigation
Kentucky	Powering the Kentucky bio-economy for a sustainable future
Louisiana	Developing a consortium for innovation in manufacturing and materials
Maine	Sustainable ecological aquaculture network
Mississippi	Complex systems - computational, chemistry, biology and biosystems
Missouri	Effects of climate change on plants and communities on a local scale
Montana	Ecosystems and cyberinfrastructure
Nebraska	Center for root and rhizobiome innovation
Nevada	Renewable (solar) energy and water resources
New Hampshire	Future of dams and safe beaches and shellfish
New Mexico	Alternate energy
North Dakota	Innovative and strategic program initiatives for research and education
Oklahoma	Social-ecological systems and sustainable adaptation to climate variability
Puerto Rico	Functional nanomaterials research
Rhode Island	Tracking changes in the marine life and ecosystems
South Carolina	Biofabrication of human organs
South Dakota	Biosystems networks and translational research
Vermont	Resilience to extreme events in the Lake Champlain Basin
Virgin Islands	Evolutionary patterns and processes, ocean and coastal processes
West Virginia	Bionanotechnology for public security and environmental safety
Wyoming	Environmental hydrology and geophysics

Definition of Terms

To ensure that terms are used consistently and that there is a common framework for the discussion of team science management, the following definitions from the NAS study were used throughout this dissertation:

- Team science – Scientific collaboration, i.e., research conducted by more than one individual in an interdependent fashion, including research conducted by small teams and larger groups.
- Science teams – Most team science is conducted by 2 to 10 individuals, and are referred to as science teams.
- Larger groups – More than 10 individuals who conduct team science as larger groups. These larger groups are often composed of many smaller science teams, and a few of them include hundreds or even thousands of scientists.
- Team effectiveness – A teams' capacity to achieve its goals and objectives. (National Research Council, 2015).

Problem Statement

Science teams are complex adaptive systems in that they work across different scales, involve multiple actors with various goals and priorities, and reflect emergent properties as interaction among members evolves over time. As a result, they are a challenge to manage and require people with substantial skill sets and an understanding of team science to maximize research effectiveness. And, as teams have increased in number and size, the position of manager has become more prevalent and therefore important to define and comprehend. The team science community currently lacks a clear understanding of what it takes to effectively manage these complex team science endeavors.

This dissertation will consider the following research questions:

- What are the key competencies (values, attitudes, beliefs, skills and knowledge) needed to manage large, interdisciplinary team science programs?

Sub-questions include the following:

- How do institutions that are hiring team science managers and related positions define the requisite competencies?
- Is there a difference between the competencies defined in this study and those being promoted by higher education institutional hiring practices?

Chapter 2 Literature Review

Theoretical Background

Constructivist Realism: Ontology

The approach to this research is framed by a distinct methodology with specific procedures as well as underlying philosophical assumptions, a basic set of beliefs or worldview, that guide the author in this research process. The ontology that frames this research is that of constructivist realism because of the fact that it encompasses both positivist and constructivist approaches to social science research. Positivists (or post-positivists) and constructivists appear to sit in very different locations of the ontological spectrum and have traditionally been thought to have irreconcilable differences, however constructivist realism provides a meeting place that allows the researcher to consider a research design that acknowledges the importance of both approaches.

Post-positivists “hold a deterministic philosophy in which causes (probably) determine effects or outcomes. Thus, the problems studied by the post-positivists reflect the need to identify and assess the causes that influence outcomes, such as those found in experiments” (Creswell, 2014, p7). Quantitative research often uses a post-positivist lens that begins with a theory, collects information through careful observation, and believes that ideas can be reduced into discrete, testable units.

Constructivism (or social constructivism) is a decidedly different philosophy that is typically used in qualitative research. “Social constructivists believe that individuals seek understanding of the world in which they live and work…The goal of the research is to rely as much as possible on the participants’ views of the situation being studied” (Creswell, 2014, p. 8).

Researchers typically use broad, general, open-ended questions to acquire information and believe that the meanings of experiences are shaped through historical and cultural norms and ongoing interactions with other people. Instead of beginning with a theory, constructivist researchers develop a theory or a pattern or meaning by listening carefully to how people describe their lives in answer to the research questions. Constructivists make sense of the world that people have constructed by understanding the context of the participants, gathering information personally, and interpreting the information that has been acquired. The mixed methods research design in this study that grew from the fundamental assumptions of the researcher and include both quantitative and qualitative elements require an underlying ontology that encompasses elements of both the post-positivist and constructionist approach.

Constructivist realism does just that. It provides a means to acknowledge the importance of both quantitative and qualitative methods in research design and posits that experiences are understood as crosscutting phenomena that span the physical, social and personal worlds. Specifically, real phenomena do take place (positivistic) and may be observed by people within and outside of an identified community. Those outside the community can approach the phenomena empathically by trying to understand the dynamics holistically and from the perspective of the community members. Or, they can take a sympathetic approach and express an interest to work in conjunction with community members (constructivist). Each approach has limitations. In the empathic approach when the researcher tries to take a community-based perspective, there will be assumptions made in the search for meaning. In the sympathetic approach, precise accounting is more possible but details may not be as easy to discern and subtle meanings may be missed.

Quantitative method can yield insights to the extent that evocative stimuli design are presented to relevant groups and the resulting statistical interactions help tease out the underlying processes. Statistically significant *effects* can draw our attention to socially meaningful *events* which are then re-examined in descriptive depth. This interplay between descriptive richness and experimental precision can bring accounts of social phenomena to progressively greater levels of clarity. Together, qualitative and quantitative methods provide complementary views of the phenomena and efforts at achieving their reconciliation can elucidate processes underlying them. *Constructivist realism* is an ontological position that accommodates the best of positivism and interpretivism (Cupchik, 2001).

This research design is informed by the underlying assumptions of both post-positivism and constructivism and assumes that processes and systems cut across physical, social and personal (individual) worlds and are examined both qualitatively and quantitatively. The research design offers rich descriptive qualitative accounts as well as quantitative analyses based on the data collected to arrive at results that can inform the community. Constructivist realism also assumes that both post-positivists and constructionists grapple with constructing data and identifying underlying biases associated with each approach. The main bias in this study exists because the researcher does have an existing relationship with many of the project participants. Specifically, the researcher has served as the Alaska EPSCoR Project Administrator and Associate Project Director for the past five years and has worked with Project Administrators and Directors in the context of organizing meetings, workshops and strategic planning efforts at a national level to support the EPSCoR mission. To address this concern, group concept mapping was identified as a suitable methodology as it allows for input by community experts and uses "words (created by the respondents) for units of analysis, captures relationships between concepts, and allows structure in the data to emerge based on co-occurrences of words or relational similarities rather than imposing researcher bias in the form of preconceived thematic categories" (Jackson & Trochim, 2002).

Structuration Theory: The Creation of Social Systems

While constructivist realism provides a broad foundational setting for this research project, structuration theory is the lens through which it finds a common framework of meaning. Developed by the sociologist Anthony Giddens in the late 1900's and early 2000's and modified by numerous others since, structuration theory posits that agents and systems are inextricably linked and must be examined concurrently to understand social systems (Giddens, 1984). Agents are defined as individuals or groups of people who have the capacity and freedom to act independently and make choices regarding their actions. Structure is defined as the factors that limit an agent's potential decisions such as ethnicity, social rules, and class. Structuration theory examines the production and reproduction of social systems without giving precedence to agency or structure. In addition, structuration theory requires the examination of both micro- and macro-level analysis, looking at the scale of both the individual and society.

Giddens defines a "duality of structure" as a feedback loop whereby agents undertake actions and produce structures with rules and resources and internal properties that then impact the agent. For instance, people are taught cultural norms from the time they are born and are dependent on the social structure around them to help them make choices about how to act. At the same time, however, the actions that people display serve to modify the existing social structures. The resulting social structures with rules and norms act as boundaries that help to define and restrict behavior while at the same time create possibilities for acting in various manners and thereby affecting change.

This theory is helpful in examining both the agents and the structure that are defined in this research. As agents in this study, project administrators do experience this duality of structure. In their daily working lives, they develop practices in their local environments based on the demands of the job and then modify those practices as they receive feedback from NSF program officers, their EPSCoR colleagues, supervisors at their home institutions, and others. The structure of the project administrator's group also shifts as members enter, depart and interact, and rules and regulations at federal, state and local levels change and cause the group to shift its approach. The duality of structure that Giddens identifies is clearly seen as the agents and the structure of the project administrator worlds co-evolve over time.

Communities of Practice: Social Theory of Learning

While constructivist realism provides a guiding ontology and structuration theory a lens through which the research may be viewed, Etienne Wenger's social theory of learning on communities of practice offers a conceptual perspective from both a theoretical and practical vantage point about how knowledge within a community develops over time, in this case within the community of team science administrators.

Previous theories of learning have focused on the individual as the unit of learning experiences and promoted the idea that learning happens in a classroom as the result of a teacher delivering information to students. Wenger's ideas about communities of practice, however, focus the learning unit on the community and a process that takes place within the context of our everyday lives in the real world. This approach assumes that learning is a participatory social phenomenon and reflects the central notion that people leading EPSCoR program management form a distributed community where learning happens over space and time. The participatory aspect of this theory has implications for what it takes to understand and support learning both for individuals and communities. For individuals, learning requires engaging in and contributing to community practices, and for communities, learning requires a refinement of practices and supporting the ongoing addition of new members.

Wenger's ideas form a conceptual framework from which to derive basic principles and a deeper understanding of how learning takes place. This framework is based on four premises:

1. We are essentially social beings … and this fact is a central aspect of learning.
2. Knowledge is a matter of competence with respect to valued enterprises … such as discovering scientific facts, fixing washing machines, writing poetry, being convivial, growing up as a boy or a girl, and so forth.
3. Knowing is a matter of participating in the pursuit of such enterprises, that is, of active engagement in the world.

4. Meaning – our ability to experience the world and our engagement with it as meaningful - is ultimately what learning is to produce. (Wenger, 1998, p. 4)

These foundational ideas reflect the primary focus of this theory on learning as a social event in which participation matters. “Participation here refers not just to local events of engagement in certain activities with certain people, but to a more encompassing process of being active participants in the practices of social communities and constructing identities in relation these communities” (Wenger, 1998, p. 4). A social theory of learning must also include elements of socialization into the learning process, and this is done through the following components: meaning, practice, community and identity.

Meaning refers to our individual and collective experiences, our ability to make sense of everyday life. Specifically, meaning develops through the interaction of two processes, participation and reification, “giving form to our experience by producing objects that congeal this experience into ‘thingness’” (Wenger, 1998, p. 59), that form the foundation of learning and practice. The negotiation of meaning implies an active process that is both dynamic and historical and has a lasting but adaptive quality. Living meaningfully also implies an ability to affect and be affected through the engagement of multiple factors and perspectives. In summary, Wenger, intends “the term negotiation to convey a flavor of continuous interaction, or gradual achievement, and or give-and-take” (Wenger, 1998, p. 53). This idea is central to the EPSCoR Project Administrators group in that there is historical knowledge about what it takes to manage these large team science projects as well as ongoing development of knowledge as rules change and people move in and out of the group. This concept also reflects the basic tenets of structuration theory in that the agents and the structure are forever in a dance of mutual impact.

Practice is "a way of talking about the shared historical and social resources, frameworks, and perspectives that can sustain mutual engagement in action" (Wenger, 1998, p. 5). As people engage with one another in common pursuits they develop a collective sense of the world and learn. As time goes by, these interactions lead to a shared sense of understanding and a community of practice created by the people within that community.

Community is "a way of talking about the social configurations in which our enterprises are defined as worth pursuing and our participation as recognizable as competence" (Wenger, 1998, p. 5). Without community, there can be no practice. By grounding this theory in the idea of community, Wenger does two things: differentiates the concept of practice from terms such as culture, activity or structure and defines a certain type of community – a community of practice. The relationship between community and practice is important here and can be defined along three different dimensions: mutual engagement, joint enterprise and shared repertoire. Specifically, practice does not exist in a vacuum; it requires a community where people are engaging one another and negotiating meaning through communication. It is the result of a collective enterprise that requires mutual engagement and results in relations of mutual accountability that in turn serve to promote the ongoing practice.

Finally, identity is "a way of talking about how learning changes who we are and creates personal histories of becoming in the context of our communities" (Wenger, 1998, p. 5). Identity in this sense refers to both the individual and the collective and the mutual forces interacting on one another and parallels the ideas that define the notion of practice. “Our practices deal with the profound issues of how to be a human being. In this sense, the formation of a community of practice is also the negotiation of identities” (Wenger, 1998, p. 149). Identity formation is formed through a negotiated experience of self that includes participation and reification, membership in a community, a learning trajectory, a nexus of memberships in multiple groups, and a belongingness that is defined globally but experienced locally.

Communities of practice, as presented through a social theory of learning, provides a relevant conceptual framework on which to hang the fabric of this dissertation. The NSF EPSCoR project administrators group finds meaning as a community of practice through the negotiation of experiences at face-to-face meetings two or three times annually. Membership is defined through the identification of a project administrator in each jurisdiction who is responsible for effective and efficient project administration, the details of which will be discussed in a later section. There is a learning trajectory that takes place for each project administrator over time but also for the community as a whole. As rules and regulations change, people find new ways of carrying out work and defining processes, and information is shared and discussed in both virtual and live meetings. Each project administrator belongs to numerous groups, interacts with multiple people throughout the course of their careers, and both teaches and learns information within the community of practice.

Current Team Research

This study examines the developing community of practice around interdisciplinary team science project management that has evolved through the advent of the NSF EPSCoR program and uses the ontology and theories previously detailed as a guiding framework. Recent research activity in the field of the science of team science informs the approach to this study and provides a starting point from which to refine the research questions. EPSCoR team science managers and others managing multi-team projects should be aware of this research and strive to incorporate its findings into practice. On the other hand, EPSCoR managers are developing a community of practice based on a shared understanding of what is important and how to perform this job. This research focuses on the nexus of practice and research in order to develop a better understanding of what it takes to manage large, interdisciplinary team science programs that are able to effectively reach their goals.

As mentioned in chapter one, team effectiveness refers to the ability of the team to achieve its stated goals. To promote and manage effective science teams, managers must understand the key components of an effective team and the processes that individual members rely upon in order to complete individual work within the framework of the team such that the overall team is successful. Three prime factors are inherent in all teams and are at the core of empirical and theoretical research on team science. First, teams are inherently multilevel. EPSCoR teams, for instance, are composed of individuals and teams, but they are also influenced by institutions, state and federal forces. In addition, most EPSCoR researchers are also involved with other research projects or even other teams within their institutions or their fields of discipline. Recent research has indicated that the degree to which a scientist is included in a team is positively directly related to team performance (Cummings & Haas, 2012). Second, teams have complex workflow structures (Steiner, 1972). An individual scientist relies only on herself to complete the tasks and attain her objectives, while a member of an interdisciplinary team relies on others. Complex programs such as EPSCoR are defined by collaboration and feedback links, creating a complex workflow structure with dependencies. A third key factor of team science is the evolution of the team over time. Emergent characteristics develop from interactions and feedback loops among individuals over time (Kozlowski and Klein, 2000) that lead to unique characteristics of the team as it evolves.

Team Processes

Teams operate through the coordinated efforts of team members in order to successfully reach the goals and objectives of the project(s). Processes can be categorized as cognitive, affective and behavioral, and when these are working in conjunction with one another, the team functions well and work progresses smoothly. If not, these provide a basic level on which to examine the problems and propose solutions and interventions.

Cognitive team processes include team mental models, transactive memory, interactive team cognition, team climate, and psychological safety. Team mental models can be thought of as the shared understandings about what it will take to make the team successful. “According to this position, effective team performance requires that team members hold common or overlapping cognitive representations of tasks requirements, procedures, and role responsibilities” (Cannon-Bowers, Salas, & Converse, 1993). On the other hand, transactive memory refers to the unique knowledge that each team member brings to the team and the ability of each team member to identify who knows what across the team (Lewis, 2003, 2004).

The presence of shared mental models has been shown to increase team effectiveness, and recent work on both mental models and transactive memory indicates that various strategies can be taken to positively impact the development of these models and promote increased team effectiveness. Specifically, training, leadership and shared or common experiences can be crafted to enhance the development of teams and the mental models that they develop early in their existence (Kozlowski and Ilgen, 2006). Vogel et al. (2014) report that taking part in activities such as developing a mutual understanding of the team's primary objectives and actively defining goals and objectives with other team members increased the chances of the team being able to carry out their research projects.

In addition to team mental models and transactive memory research that focuses on where the knowledge is located and how it is arranged across the team, interactive team cognition refers to the communication of knowledge among team members. Disciplinary knowledge is critical, however the ability to communicate thoughts and ideas is essential to effective team processes. Teams must share knowledge among members in order to attend to higher level tasks such as decision-making, problem solving, situation assessment, and planning (Letsky and Warner, 2008). This interdependence is key to team cognition and may be more responsible for team success than the actual knowledge streams from members (Cooke, Gorman, Myers, and Duran, 2013). Recent research is examining the explicit communication among team members in part because, as opposed to internal cognitive processes, communication can be observed and studied across the lifetime of a project.

Team climate and psychological safety, both of which refer to perceptions among team members, are the two final factors identified as critical components of effective cognitive team processes. Team climate is based on the strategic values of the team or organization and varies according to the mission of the team. A team with a goal of capturing market share has a different climate than a team with the goal of maximizing community partnerships. Climate develops through the interactions of team members over time as they work toward their goals and objectives. Leaders can impact team climate through communication and management strategies (Kozlowski & Doherty, 1989). Psychological safety has to do with the shared perception based on how team members view the willingness of the climate to support risk taking and the acquisition of new skills and knowledge. Taking risks and making errors is an inherent part of the scientific research process, and learning from the ensuing information propels the advancement of science. Team leaders can impact this facet of team cognition by fostering an inclusive environment, diffusing conflict, and reducing power differentials (Edmondson, 2003). "Thus, the research base suggests that appropriate team leadership is a promising way to promote psychological safety, learning, and innovation in science teams and larger groups." (National Research Council, 2015, p. 67).

Team science leadership needs to consider the motivational and affective team conditions as well as the aforementioned cognitive processes. Key factors along these lines include team cohesion, team efficacy, and team conflict, all of which have been shown to impact team effectiveness. Team cohesion typically refers to task commitment and social relations. The preponderance of research has been on team cohesion with results concluding that team cohesion is positively related to team effectiveness. Teams that have strong cohesion and are more effective tend to have strong interdependencies (Gully, Devine, and Whitney, 1995). While team cohesion appears to be strongly related to effective team outcomes, little research has been done on how to develop and enhance team cohesion so leaders currently do not have a plethora of resources from which to draw when considering how to positively impact team cohesion.

Team efficacy, or similar, shared perceptions are also positively related to team performance when team members are highly interdependent (Gully, Incalcaterra, Joshi, and Beauien, 2002). Strong teams with high self-efficacy ratings are able to set loftier goals, persevere in the wake of setbacks and challenges, and provide a high level of effort to attain the shared goals and objectives. Team leaders may consider identifying prospective team members who share these types of self-efficacies in order to increase team effectiveness, and they may provide opportunities for team members to establish these traits through experiencing success, providing realistic positive feedback, and convincing a team that it has high efficacy characteristics (Kozlowski & Ilgen, 2006).

Another dimension of teams that impacts effectiveness is that of team conflict related to relationship, process or task. There is currently debate as to whether all of these types of conflict pose a threat to team science projects. A recent meta-analytic study by deWit, Greer and Jehn (2012) suggests that conflict may not be detrimental under some situations and that further research is needed to understand when conflict may pose a positive force within teams. Team science managers who are aware of potential sources of conflict and have the skills and knowledge to help the team avoid conflict or deal with it when it arises are better equipped to promote successful projects.

Team behavioral processes join the previously described cognitive and motivational processes as topics that team science managers need to be aware of in order to maximize team effectiveness. Team process competencies, which include the individual competencies such as the knowledge and skill base related to teamwork and team motivation and regulation, are similar to the individual processes discussed earlier but take place at a team level. Factors to consider include behavioral processes, interpersonal factors, and overarching team processes. Team self-regulation impacts resource allocation within the team and the efficacy of the team as a whole. Team science managers look to interventions that measure team productivity and provide feedback such as the Productivity Measurement and Enhancement System developed by Pritchard and others (Pritchard, Jones, Roth, Stuebing, and Ekeberg, 1988).

Models of Team Science

Current research on modeling team science is building on these studies of team processes and developing new ways of thinking about team science leadership. “Research has shown the influence of leadership on team and organizational effectiveness. Most of this research however, focuses on the leader, rather than the team, and measures the effectiveness of the leader based on individual perceptions rather than measuring team effectiveness…There is also promising new work on the concept of shared leadership by all team members” (National Research Council, 2015, p. 74). For instance, Wang, Waldman and Zhang (2014) conclude that there is a positive relationship between shared leadership and team effectiveness. This may prove especially helpful when thinking about leadership of large teams or teams of teams such as found in EPSCoR jurisdictions.

With the rise in the number of science teams and the percentage of science research undertaken by teams today come new theories and models. Traditional ways of looking at team and group development start with a well-known model that identifies specific phases of team development: storming, norming, forming, and performing (Tuckman, 1965). While this model focuses on smaller teams than those found in EPSCoR jurisdictions, this developmental sequence is frequently referenced in team science literature. Two recent models expand on this work to incorporate additional characteristics of teams that are critical to understanding large team development and effectiveness. These factors include an understanding of interdisciplinary science research and the methods required to design programs that are able to tackle our large, complex societal problems.

The first of these two models was developed by Kara Hall at the National Institutes of Health (NIH). Hall et al. (2012) underscore the importance of the primary developmental stages of teamwork and focus on the positive impacts of early planning and effective support mechanisms that should be methodically established at the beginning of the project. Four phases are defined in this model: development, conceptualization, implementation, and translation. The development phase begins with narrowing down and defining the problem, reviewing the research area and identifying the specific areas of expertise that are required to address the problem. During this stage the team develops shared missions and goals, creates visual representations of the project, and begins to identify the strengths and weaknesses of each discipline as it pertains to the overall objective. This is also the stage in which trust among team members begins to develop, setting the foundation for an environment that promotes safety and collaboration.

The second phase, conceptualization, is the time for developing the research question and sub-questions, hypotheses, the conceptual framework and a research design. Teams focus on creating an environment of collaboration and an understanding of the interdisciplinary or transdisciplinary approach to addressing the research question. Specifically, members work to communicate without disciplinary jargon and establish a shared language with common terms to facilitate effective communication. Team self-efficacy and transactive memory are established and continue to grow and develop over time.

In the third phase, implementation, the team comes together to do the work of the project and brings in people beyond the initial core members. Standards are set for meeting times and frequencies, and conflict management becomes important. A shared understanding of team processes and teamwork are important at this stage and may become a focus of conversations to increase team capacity and effectiveness. Conceptual frameworks and mental models may be refined and modified in an iterative process to reflect ongoing work.

In the final phase, translation, the team communicates findings to a broader audience, applies results to policies and actions and impacts societal constructs. Shared mental models and transactive memory is important during phases three and four as new team members join the team and other team members move on to different projects. Challenges may occur as team members connect with external stakeholders who are interested in the findings but have not yet been involved with the project. This model can help steer team science leaders and evaluators through a complex project and provide a lens through which to consider interventions.

The second of these recently developed team science models is that of Salazar et al. (2012). Integrative capacity is at the core of this model and refers to the capacity of a team to "work across disciplinary, professional, and organizational divides to generate new knowledge…through the continuous interplay of social, psychological, and cognitive processes within a team" (Salazar et al., 2012, p. 22). The authors define the integrative capacity through three different conduits.

Social integrative processes is the first of these pathways and involves such facets as shared understandings of the project goals and objectives, leadership practices, communication strategies, and elements of transactive memory such as the distribution of disciplinary expertise that members bring to the team and the shared understanding of who knows what.

The second piece of this model outlines the means with which teams embrace these social processes and develop a sense of trust and connection. Leaders can impact this stage of team development with specific interventions that can lead to increased effectiveness. These emergent states come about as social processes progress toward increased cognitive collaboration across the team.

Third, "these social processes and emergent states facilitate the cognitive processes of knowledge consideration, assimilation, and accommodation, leading, in turn, to continued growth of the team's integrative capacity" (National Research Council, 2015, p. 77). Team leaders can support this stage by encouraging members to collaborate and communicate with one another and think about how their knowledge can support and be supported by that of others to move toward the goals of the team and find new ways of thinking through integrative science. Reflexivity, the ability of team members to reflect on their own participation and knowledge, is important to the overall preparedness and capacity of the team to work through complex problems in interdisciplinary and transdisciplinary team settings. These two models can help team science leaders consider the states of their own teams and what kind of support or interventions might be most effective at various times across the lifetime of a project.

Team Science Competencies

Over the past two decades, researchers have invested time into team science by investigating team processes, identifying stages of team development, posing models of team science, and beginning to define competencies for researchers participating in science teams. While additional rigorous studies need to be done in the area, these recently proposed competencies are an important first step in understanding how to educate team science participants, develop interventions, and begin to build a framework of competencies for team science leaders. These team science competencies serve to inform the research on team science leadership and what the associated competencies may embody.

Team Leadership and Management

Effective teams require effective leadership and management, and while specific competencies for team science leaders have not yet been identified, there has been significant research on organizational leadership on teams in corporate, military and sports settings. A literature review on this subject shows a variety of approaches for defining leadership and management, and upon review, the National Academy of Science consensus study on team science agreed on an approach that is adopted in this study as well. "Recognizing that it is difficult, if not impossible, to draw a strict line between leadership and management, we have not attempted to completely disentangle the two functions" (National Research Council, 2015, p. 126). NSF does not prescribe specific leadership and management structures for the jurisdictions. Each state has the freedom to define the leadership structure best suited to address its needs, but all identify multifaceted leadership and/or management roles, many of which involve multiple people with shared or overlapping responsibilities. In fact, the NAS study states that "Understanding ways in which more traditional and hierarchical leadership may be used in conjunction with more participative, shared or otherwise emergent forms of leadership is particularly relevant for effective leadership of science teams and groups" (National Research Council, 2015, p. 129). For these reasons, this study will adopt the NAS approach and deliberately avoid the strict distinction between leadership and management.

The literature on leadership contains a vast wealth of information about general leadership theories and practices, quite a bit about team leadership and much less about team science leadership (Asencio et al., 2012; DeChurch et al., 2011; Marks, Mathieu, & Zaccaro, 2001). A brief summary of these successively narrow topics provides the building blocks for this study and helps to situate the research questions. Leadership theory first started in the mid nineteenth century with the Great Man Theory by Thomas Carlyle that assumed that leadership traits were intrinsic and that great leaders were born with the skills to become great leaders. In the 1930s, the Trait Theory became popular and stated that people are born with specific leadership traits such as intelligences, creativity, and a sense of responsibility. This phase focused on analyzing the mental, physical and social characteristics of individuals to find the common threads that define great leaders. By the 1940's research was shifting from traits to behaviors as the defining parameters for great leadership. Leaders were categorized into two groups: one concerned about people and the other concerned about tasks, a common theme in much of the subsequent leadership literature. The Contingency Theory emerged in the 1960's and argued that leadership should be dependent on the situation at hand and that a leader is more apt to step into a leadership role if she believes that followers will show their support. In the 1970's, Transactional (or Exchange) Leadership Theories became popular and led to the theory of Leader-member

Exchange. These theorists believe that a mutually reinforcing environment is important to the success of organizations and that the effective leader and his followers must assume the same goals with positive feedback mechanisms for developments that move the organization forward and negative feedback for setbacks. At approximately the same time, Transformational Leadership Theories began to emerge. The essence of Transformational Leadership, one of the most pervasive significant theories in recent times, focuses on leaders who create solid relationships that result in trust and subsequently transform their followers through inspiration, charisma and individual attention. The contingency approach to leadership, first established in the 1950's, has led to the development of the more recent contextual approach to leadership. Contingency proponents believe there is no single way to lead and that organizational behavior and therefore leadership depends on the environment in which the organization operates. As the name implies, the contextual approach recognizes that the context of every leadership situation is somehow unique and requires a particular set of approaches, skills and tools. The emphasis on unique contextual circumstances such as found in complex science programs such as NSF EPSCoR, make this a relatively attractive approach for team science leadership. Each EPSCoR state is defined by a unique set of institutions of higher education, state research and development needs, and resources. These fundamental criteria help to build the foundation of each state's EPSCoR program and set a trajectory for a unique set of opportunities and challenges that require a flexible approach to leadership and management that may not be dictated by a single generic prescriptive approach. "For example, the contextual circumstances of a particular team might require shared leadership, in which leaders share leadership roles, functions, and behaviors among team members" (National Research Council, 2015, p. 129).

Over the past several decades, the issue of leadership has been an important topic for people studying team effectiveness. These findings (National Research Council, 2015) provide a good place for the science world to examine potentially similar features and processes and extrapolate the findings to research on team science. Leaders can influence the team processes mentioned previously that are important factors for effective team functionality including team mental models, team climate, psychological safety, team cohesion, team efficacy and team conflict. Studies have shown that leadership can positively impact each of these processes through specific actions such as coaching, modelling behavior, encouraging inclusion, anticipating conflict, reducing power differentials and more (National Research Council, 2015). Some actions may take place when a problem arises, but others may be preemptive and occur before the team begins its work.

Team leadership requires that a leader be actively involved through directing and coordinating activity, planning and organizing, assessing performance, motivating members, and creating a positive environment in which the team operates (Salas, Sims, and Burke, 2005). This mode of thinking about team actions supposes that teams are always in a state of flux, and leadership is an endeavor that is constantly adapting as factors that influence the team evolve over time. It requires that a leader is adept at recognizing the team processes and able to adapt to an ever-changing environment. "Given the dynamic nature of scientific research, leaders of science teams and groups may be more successful if they adopt a dynamic or functional leadership approach, are psychologically agile, and can use appropriate and varied modes of communication to engage with people from multiple generations, backgrounds and disciplines" (National Research Council, 2015, p. 132). Research carried out at the Center for Creative

Leadership proposes a dynamic approach to leadership that includes setting direction, creating alignment, and building commitment (Drath et al., 2008) and that the source of leadership could be a single individual or multiple people or factors. Dynamic leadership approaches challenge leaders to both promote adaptive capabilities as teams learn and grow and recognize the necessity for collective leadership (Day, Gronn, and Salas, 2004). Especially important to the EPSCoR programs that involve multiple teams, Tannenbaum, Mathieu, Salas and Cohen (2012) found that large team projects with numerous people require a distributed or shared leadership structure that might involve shifting to a more self-managed system and developing opportunities for others to learn leadership skills. Other research efforts are looking at team "faultlines", the boundaries that develop between and within teams that prohibit the team from reaching maximum success (Thatcher and Patel, 2012). Faultlines that lead to team conflict need to be managed through processes such as establishing common goals, norms or cultural values, creating a task reward system, or finding common ground by leveraging external conflict and deemphasizing or shifting focus from the internal conflict.

Science teams share characteristics with teams in other contexts. Current research in team science leadership and management shows that good leadership and management practices can positively impact team effectiveness and outcomes. Some of the most recent models of team science management promote the use of shared leadership in collaborative, interdisciplinary projects (Gray, 2008) such as those found within the EPSCoR program. Research on other projects, however, suggests that a combination of hierarchical and shared leadership may be most effective (Hackett, 2005), reflecting the reality that many team science leaders serve in multiple positions including researcher, mentor, administrator and teacher. As a result, team science leaders may require training in a variety of leadership and management techniques that allow them to adapt to different and changing circumstances, much like the dynamic leadership processes mentioned earlier. There has been little research on multi-team science program leadership and management. One study that focused on disaster relief systems noted that behaviors of leaders and managers that promoted effective processes included developing overall strategies and coordinating the activities among the different teams (DeChurch et al., 2011). This conclusion seems fairly obvious based on current literature on team research. The two team science models identified earlier in this section, those of Salazar and Hall, address many of the factors that research on leadership show are important. Finally, scientific expertise is seen as critical in the ability of a transdisciplinary team leader to communicate the goals by visioning and framing ideas for others. "Transdisciplinary leaders need to be able to envision how various disciplines may overlap in constructive ways that could generate scientific breakthroughs and new understanding in a specific problem area. They themselves need to appreciate the value of such endeavors, be able to communicate their vision to potential collaborators, and construct a climate that foster this collaboration" (Gray, 2008, p. S125). The expert knowledge of EPSCoR team leadership and management can add substantial evidence to the current body of knowledge about what it takes to lead large, interdisciplinary team science initiatives.

Chapter 3 Methodology

Introduction to the Research Design

This research focuses on defining conceptual categories and key competencies for people in positions of managing large, interdisciplinary team science programs. Using a mixed methods approach, the research relied on the expert knowledge of seasoned team science managers as the basis for constructing a competency framework. This framework was then used as a baseline to analyze current hiring documents including position descriptions and announcements for positions that included some responsibility for working with large, interdisciplinary science teams. The final section integrated results from the group concept mapping analysis with the content analysis to compare the competency set developed by team science experts with current hiring practices.

This study incorporated a mixed-methods, exploratory, sequential research design (Creswell, 2014) and employed both quantitative and qualitative research tools (Figure 3).

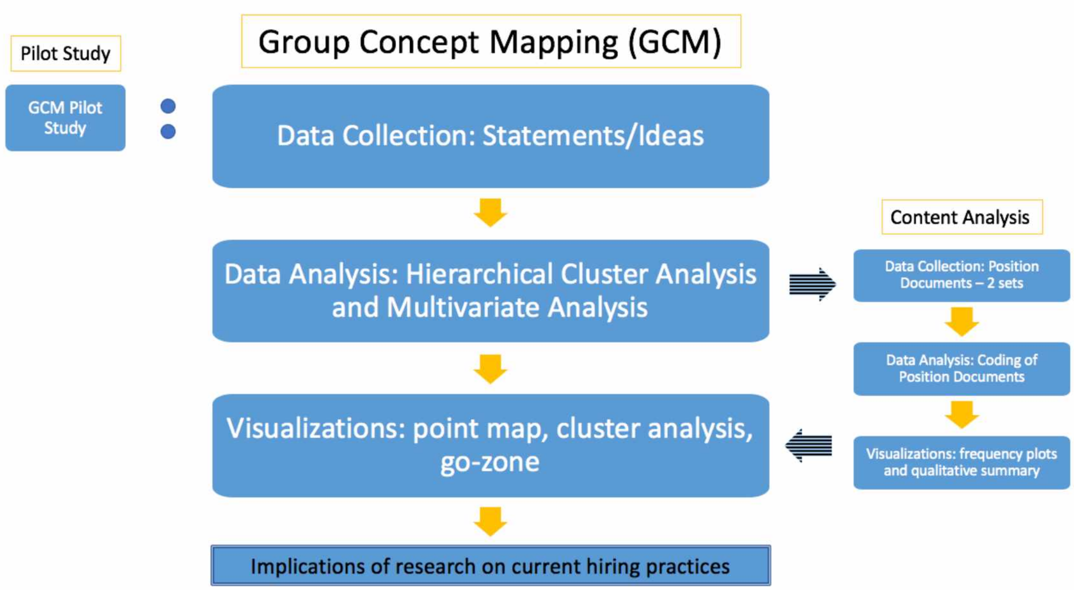


Figure 3. Research design diagram illustrating the group concept and content analysis portions.

The first section of this research utilized group concept mapping that was in and of itself a mixed-methods approach. Qualitative data were collected through a brainstorming session using the Concept Systems GlobalMax software with expert team science personnel from state-based EPSCoR projects. The data were then sorted and rated by each participant, and the resulting matrices were analyzed using multivariate statistics, a quantitative means of examining the relationships of ideas generated by the group of experts. The resultant information was then used to identify clusters of concepts in a qualitative manner. The second section of the research was a qualitative analysis of document content using the software package ATLAS.ti. The information generated in steps one and two provided for both qualitative and quantitative comparisons using the data from the group concept mapping section and that generated from document analysis.

As noted in the Introduction, this dissertation considered the following research questions and sub-questions:

- What are the key competencies (values, attitudes, beliefs, skills and knowledge) needed to manage large, interdisciplinary team science programs?

Sub-questions include the following:

- How do institutions that are hiring team science managers and related positions define the requisite competencies?
- Is there a difference between the competencies defined in this study and those being promoted by higher education institutional hiring practices?

The first step in this research project was to capture and organize the expert's ideas about the competencies required to manage large, interdisciplinary team science projects without assuming preconceived ideas about what the framework might entail. Group concept mapping provided a fitting approach to examine this information from the perspective of EPSCoR management experts. This information was organized into conceptual groups of ideas and created a foundation for a competency framework. This methodology is both quantitative and qualitative in nature and led to both descriptive and numerical results based on the qualitative input. Previous studies examining frameworks for practice in a variety of different fields inform this research and support the decision to use the CS GLobal MAX group concept mapping software (Slonim, Wheeler, Quinlan, and Smith, 2010; Smith & Mireles, 2010).

> [Concept mapping] appears to be especially well suited for the following types of organizational research questions: (a) when the researcher does not want to impose bias or suggest relationships by forcing the data into a preconceived coding scheme or (b) when existing coding schemes or theoretical frameworks do not already exist or when the purpose of the research is to explore possibilities for conceptual categories… (Jackson & Trochim, 2002, p. 333).

The second part of the study involved an examination of documents through content analysis using ATLAS.ti, a Computer-Aided Qualitative Data Analysis Software (CAQDAS) to support the processing of qualitative data. In this case, the data consisted of more than 100 job descriptions captured over the past 5 years that represent positions in higher education institutions across the United States that are involved with the management of large scientific research efforts. The concept group titles developed through group concept mapping were used as the codes for the content analysis. Each statement in each document was coded by the categories into which it best fit. Statements that spanned more than one conceptual grouping were assigned multiple codes.

In preparation of this research, an Institutional Review Board (IRB) protocol application was developed and submitted to the UAF IRB for review. After minor amendments suggested by the board, the protocol was approved through an exempt review process (Appendix A). An informed consent form was drafted for both the pilot study and the final group concept mapping exercise (Appendix B).

Participants

The group concept mapping part of the research relied on the knowledge of seasoned team science management experts, current practitioners who have developed a community of practice and have worked together to define a set of best practices through active employment and engagement with others in this nascent field. Due to the relatively recent increase in the number and sizes of science teams (Wuchty et al., 2007), there did not currently exist a standard framework of competency for team science management positions. The National Academies of Science study suggested that team science management practices should be informed by existing literature from the business and military world (National Research Council, 2015). While this was an excellent strategy, the NSF EPSCoR program that consisted of 28 individual state-based capacity building programs across the United States and its territories already held a collective wealth of knowledge about team science management from which to draw. Each of these programs represented a major collaborative effort to perform scientific research, increase statewide research capacity and support numerous students, faculty, administrators and stakeholders to address large scale, state-based research needs.

Over the past several decades, these programs evolved to resemble NSF Science and Technology Centers in scope and complexity. As the programs evolved, there was a resulting shift in the approach to team management. When the program was initiated in 1980, Principle Investigators hired Project Administrators (PAs) to assist with program management, and while that title still exists, positions with titles such as Associate Project Director and Project Manager have become more prevalent, suggesting a shift in management strategy toward shared leadership responsibilities and a recognition of increased complexity in the management of these large, complex, team science programs. The participants in this study hail from the cohort of EPSCoR leaders that include Project Directors, Associate/Assistant Project Directors, Project Managers, Project Administrators and Education, Outreach and Diversity Managers.

Method: Group Concept Mapping

The term "concept mapping" refers to the ability to produce a visual representation of ideas and concepts generated by people. Group concept mapping is a mixed-methods, participatory approach that includes activities such as brainstorming, rating and sorting ideas, and statistical calculations such as multidimensional scaling and hierarchical cluster analysis.

Since its inception in the late 1980's, group concept mapping has been popular in studies related to health care issues and used as a research tool at the National Institutes of Health (NIH). GCM can be broken down into six specific steps. First, a focus for the project is defined, participants are identified and invited to participate, and the logistics that include a detailed timeframe are developed. The second step is to gather ideas about the topic in a brainstorming session that can be done face-to-face in a live session or virtually using the Concept Systems CS Global MAX software. Third, ideas are synthesized and participants sort and rate each idea based on one or more variable of interest as defined by the researcher. In many studies, these variables have included parameters such as importance and feasibility. Fourth, the software creates plots, or maps, in which each idea is represented by a single point. The placement of each point is determined through a sequence of multivariate statistical analyses with the resulting map revealing a best fit and illustrating how each point is relatively connected to each other point. Fifth, participants are invited to interpret the maps and confirm that the grouping of ideas into concepts is valid and true. Finally, the information gained through group concept mapping such as maps, graphs and tables, are used to address the research questions.

Group concept mapping was used as a tool in the first section of this research project as a mechanism to initiate a robust dialog with people leading interdisciplinary team science projects and as a means to stimulate critical thinking about what it takes to manage these programs. This approach created a framework for a focused discussion about the topic of team science management, a means for collecting the information about what the experts deem important and the mechanism to create and display conceptual groupings in a visual format. Researchers in Ithaca, New York with Cornell University and Concept Systems, Incorporated developed, promoted and utilized the methodology of group concept mapping and created a software package, CS GlobaMAX, that allows researchers to collect and analyze data.

One of the first steps in the group concept mapping section was to develop a focus prompt for the brainstorming session. This prompt was a direct result of the research question(s) and provided a focal point for the brainstorming activity. As with all group concept mapping projects, the prompt was written in clear, simple, descriptive language to keep the responses focused on what it takes to manage large, interdisciplinary team science projects. The specific prompt used in this study for both the pilot study and for data collection was the following: "One thing that an effective interdisciplinary team science manager needs to know or to do is…".

Group Concept Mapping: Pilot Study

This study involved two group concept mapping sessions. The first session served as a pilot study and took place at the University of Alaska Fairbanks (UAF) in April 2015. Participants included people from across the UAF campus who were involved with some aspect of managing large team science projects including science managers, fiscal personnel, principal investigators, communication specialists, education and outreach managers, and science administrators from the NSF Alaska EPSCoR, National Institutes of Health IDeA Networks of Biomedical Research Excellence (INBRE), the Office of Grants and Contracts (OGCA), the Office of Sponsored Programs (OSP), Alaska Biomedical Learning and Student Training (BLaST), Department of Energy (DOE) EPSCoR, National Aeronautics and Space Administration (NASA) EPSCoR, and others. The overall makeup of attendees included people with a broad swath of job categories and positions that team science managers regularly engage and served as a useful exercise with a diverse and responsive audience capable of providing critical feedback and relevant suggestions.

The pilot study helped to refine many of the specific details for this approach including the initial written material such as instructions and the discussion prompt, room setup and organization, timing, facilitation techniques, software and technology needs, and instructions for the sorting and rating exercises. Preliminary data analysis allowed for a first look at creating group concept mapping outputs including point maps, go-zones and pattern matches and offered a chance to walk through the process of creating each of these before the final project data was collected. Finally, a stress value for this exercise, a statistic routinely reported for multidimensional scaling that reflects the goodness of fit of the map to the original dissimilarity matrix that served as input, was calculated as an idea of the internal validity of this type of exercise.

A pilot session advisory board consisting of three UAF employees involved with team science was established prior to the start of the data collection period. Board members reviewed the protocol, assisted with technology during the brainstorming sessions, and served as part of the community that reviewed and analyzed the preliminary data.

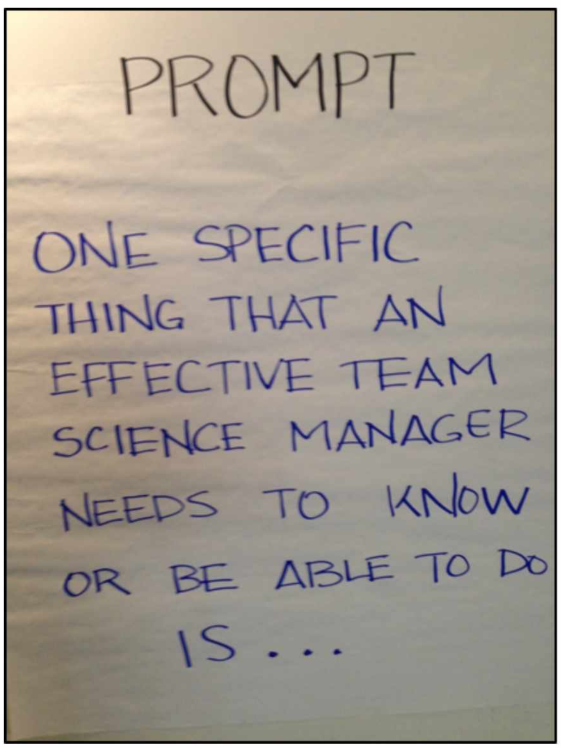
The brainstorming sessions were organized into three distinct steps:

1. Introduce the topic and define terms such as “team science”, “manager” and “interdisciplinary”,
2. Explain the research process using group concept mapping from beginning to end including brainstorming, rating and sorting and the presentation of results, and
3. Facilitate a brainstorming session using the defined prompt.

Participants were asked to brainstorm ideas to complete the above prompt. During the pilot session, responses were displayed on a large screen so all participants could see the information as it was generated. To maximize the potential of gathering a comprehensive set of ideas, the online site was left open for one week after the pilot brainstorming session so those participating face-to-face could include additional responses and those unable to attend the meeting could contribute their ideas as well. All participants were also invited to submit responses by email directly to the researcher.

Once the data collection period closed, the researcher reviewed all responses and performed the usual quality control to remove duplicate statements, separate statements into single ideas, and provide clarification when necessary. Statements were left in their original forms whenever possible. Once the quality control procedures were complete, the advisory team was enlisted to compare the original list of ideas with the final list of ideas to confirm that the ideas remained intact and that the final list was true and accurate.

In preparation for the pilot session, an outline of the session and an Idea Generation Form (Appendix C) was created in case people preferred to write ideas on paper rather than use the computer software. Two written visual aids including the prompt used to generate the discussion and the guidelines to help direct the conversation were created prior to the start of the session (Figure 4).



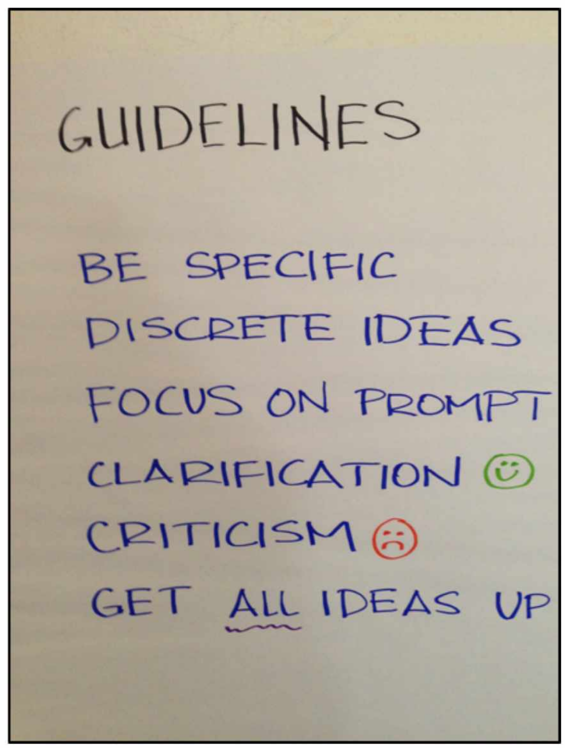


Figure 4. Visual aids created for the pilot session to remind people of the prompt statement and the guidelines for participation.

Informed consent forms and idea generation forms were distributed to all participants in case participants did not have a computer to access the data collection system on the research website. Several people who were not able to attend this session provided additional ideas through the online site in the two-week period after the brainstorming session.

Brainstorming closed on May 3, 2015, one week later than originally anticipated, as ideas were still being input into the online system. Once the session closed, data review and synthesis began in order to ensure that the information collected could be used for the sorting and rating activities. This included the following steps:

- Create a list of unique ideas, with only one idea represented in each statement.
- Ensure that each statement is relevant to the focus of the project.
- Reduce the statements to a manageable number for sorting and rating.
- Ensure that statements are clear and understandable across the entire stakeholder group.

The original list of 123 statements was reduced to 100 by the researchers and the advisory team. Participants were provided access to log in to the research site and enter their profiles for the rating and sorting exercises. Each person sorted the ideas into groups of concepts using a drop-and-drag or menu pull-down option provided on the research site. Then, each participant rated each idea on the criteria of feasibility and importance using a 5-point Likert scale.

Once the sorting and rating were complete, preliminary analysis and relevant outputs including a concept map, cluster map, spanning analysis, pattern match and go-zone were created. Validity was evaluated through a discussion of results with the participants after the data were analyzed and preliminary results were prepared. Reliability is associated with a stress value that can be calculated once multidimensional scaling is complete. The lower the stress value, the better the fit between the similarity matrix and the concept map. Typically, the stress value for group concept maps ranges from 0.10 to 0.35, and the resulting map is readily interpretable. While there are no absolute cutoffs, lower stress values correspond to better correlation between the similarity matrix and the map.

The pilot study was useful in helping to determine an accurate time period needed for the brainstorming session, the layout of the room, and fine tuning the instructions for the brainstorming session. The pilot study also allowed for a test run through the steps necessary for data analysis.

Group Concept Mapping: Data Collection

Final data collection took place in Washington, D.C. at the May 2015 meeting of Project Directors and Administrators for NSF EPSCoR. Key personnel included NSF program officers (who observed but did not actively participate), Principal Investigators (PIs), Project Directors (PDs), Project Administrators (PAs), and Education, Outreach and Diversity (EOD) Managers. The initial concept of this study was presented to these members of the NSF EPSCoR leadership community in January 2015 at the semi-annual NSF EPSCoR PD/PA meeting. An overview of the study and doctoral research goals were presented with the anticipation of running a face-to-face brainstorming session May 18-19, 2015. A subsequent trip to Washington, D.C. in March 2015 provided an additional opportunity to speak with NSF officers about the specifics of the May meeting and to help determine the timing and location for data collection.

All EPSCoR leaders were invited to participate in this study via personal contact at NSF EPSCOR meetings as well as a direct email invitation one month prior to the meeting in Washington, DC. The sessions were voluntary and scheduled to take place in the same room but directly after the NSF EPSCoR meeting. Via email, participants were asked to read and sign an online informed consent form that explained the nature of the research. The advisory team was composed of six people who hold senior management roles plus an experienced facilitator who was invited to observe the brainstorming session and provide feedback on the session after completion.

The brainstorming session was attended by 26 people: 3 NSF program officers, 22 EPSCoR leaders and John Riordan as an observer. Due to the large size of the overall group (as compared to the pilot study), participants were split into three groups with 8 or 9 people per table plus one advisory team member who served as the facilitator and another who served as scribe. The brainstorming session was introduced with the focus of the research and the steps required to complete the data collection phase. After a brief introduction and a moment of quiet contemplation, discussion commenced and ideas were collected. Each individual received an idea generation form on which to write ideas that completed the focus prompt, and the scribe recorded all ideas as the conversation at the table evolved. The session ran for approximately 60 minutes until ideas were exhausted and nothing new was being captured. Idea generation forms were collected and all of the ideas were added to the research software site. The online brainstorming session remained open for an additional month to collect ideas from people who did not attend the face-to-face session or people who did attend and wanted to submit additional ideas. An original list of 140 statements was reviewed by the researcher and narrowed to the final 120 statements. These statements were then reviewed and approved by the advisory team and incorporated into the sorting and rating exercise.

Once brainstorming was complete and all ideas collected, participants were instructed via email to return to the research site and sort the statements into piles of concepts based on their conceptualization of the interrelatedness of the items. Instructions for this activity included two restrictions: no item can constitute its own pile (i.e. no pile could have only one item) and no item can be in more than one pile. The total number of piles is left to the discretion of the participants, but a total suggested number is in the order of 10 to 20. The participants were then asked to rate each idea in the aggregated response list. Participants were asked to review the list and to rate each item based on how important they felt that item is and how feasible it is to require a team science manger to know or be able to do. Responses were framed in a five-point Likert rating scale (1 - unimportant, 2 - slightly important, 3 - moderately important, 4 - very important, 5 - extremely important).

After data collection was complete, the data was analyzed using CS GLobal MAX software. Each person's data was represented in a two-dimensional matrix that indicated which statements were grouped together. The complete aggregate set of two-dimensional matrices defined the three-dimensional matrix that was used as input to the multidimensional scaling (MDS) analysis and the subsequent hierarchical cluster analysis. As a measure of reliability, a stress value was calculated and served as a metric for measuring the degree to which the MDS solution fits the original summary matrix. The better fit of a map to the similarity matrix, the lower the stress value. Typical GCM projects exhibit stress values that fall between 0.10 and 0.35.

After the MDS and cluster analysis were performed, the researcher studied the clusters and statements and proposed a final map that accurately reflects the correct level of detail to explain the concepts. The advisory team reconvened to review the output, examine the final groupings of ideas into concepts and confirm that the titles and number of conceptual groupings made sense from their vantage point as experts in the field of team science management. This check served to address the question of reliability. The level of granularity in defining the total number of conceptual groupings was the responsibility of the community of experts, in this case the advisory team.

Group Concept Mapping: Reliability and Validity

Several papers have been written that address the reliability and validity for group concept mapping (Jackson and Trochim, 2002; Rosas and Kane, 2012; Slonim et al., 2010). The individual and aggregated sort data and the resulting distance matrices provide information that can be used to calculate reliability estimates. This can be accomplished through several different approaches. First, the group sort data can be randomly divided into two sets, and concept maps can be developed for each half. Sort matrices can be correlated using a mathematical construct known as the Spearman-Brown correlation to obtain the split-half reliability of the sort groups. Second, the sort matrices for each person can be correlated and used to obtain a reliability figure that compares individuals to one another. Third, the sort matrix for each individual can be compared to the aggregated similarity matrix to give a reliability measure that compares each individual matrix to the overall matrix. Fourth, the sort matrix for each person may be correlated with distances from the final point map to yield a reliability figure that compares the individual to the final point map. An analysis of 69 studies found that all correlations were significant at the 0.001 level.

Measures of validity are challenging to operationalize, and (Trochim, 1989) posits that internal and external representational validity are analogous in group concept mapping. And, while external validity measurements are still exploratory, measurements of internal validity refer to the degree to which the conceptualized model reflects the outcomes of the participants in organizing information about the model. So, determining the overall match between the participant input and the mathematically generated output is important to assessing validity.

Several approaches are used to assess internal validity, most notably a stress value, or goodness-of-fit, can be calculated to determine how closely the final point map strays from perfect. Analysis by Sturrock and Rocha (2000) found that a stress value of 0.39 results in multidimensional maps with less than a 1% probability of having no structure or being a result of random placement. Overall, this study showed that the validity results confirmed that group concept mapping does a good job representing a complex set of multivariate data on a two-dimensional point map.

Validity is addressed in this study through the engagement of the advisory teams. Once the data was collected and a preliminary analysis has been performed to develop a point map and possible cluster maps, the advisory team was tasked with the goal of reviewing and discussing the specific number of clusters needed to best define the concepts and the most appropriate cluster titles. Advisory team members were all seasoned experts in the field of team science management with up to 15 years of experience per person. While the population was limited to EPSCoR, this group hails from statewide research programs across 28 different states and jurisdictions. These programs span a wide range of disciplines with many focused on interdisciplinary approaches to complex societal problems. Due to the diverse and rich nature of scientific research being done across the EPSCoR programs, it was appropriate to generalize the findings to other large, team science programs, and the feedback received from the advisory team provided the information needed to confirm that the final point map retains a high level of validity.

Previous analysis by group concept mapping researchers did provide baseline data to address the questions about the methodological quality of concept mapping, concluding that concept mapping does indeed generate reliable and valid results. These results are consistent, whether the data are collected in person or online. In addition, studies have shown that quality and rigor can also be maintained for concept mapping data collected via the internet, addressing the question of whether data collected through group processes are different than those collected through other means (Rosas and Kane, 2012).

Method: Content Analysis

Part two of this research design involved contextual interpretations of textual data. Two datasets were analyzed using ATLAS.ti. Results from these analyses were then compared to the results from the group concept mapping exercise. The first set of 24 documents was collected from EPSCoR state leaders and includes position announcements and descriptions for Project Directors, Project Administrators and other EPSCoR personnel. The second set of 147 documents was collected by Dr. Holly Falk-Krzesinski, Vice President of Global Academic and Research Relations for Elsevier Publishing. Through her leadership with the annual international Science of Team Science Conference, Dr. Falk-Krzesinski has been instrumental in developing a strong community of practice for team science and interdisciplinary research. She also launched the National Organization of Research Development Professionals (NORDP), serving as the organization's founding president. Dr. Falk-Krzesinski developed a number of STEM-related career development programs with a special emphasis on early career scientists and women, and through this work collected textual documents such as position announcements and descriptions related to team science management.

Each document was examined to ensure that it conformed to the basic criteria of being a position that involved some aspect of team science. Once the quality control and assurance was complete, each document was individually loaded into the software and grouped into one of two files, the first for the EPSCoR documents and the second for the national team science positions. Steps for coding the content follow those outlined in *Quantitative Analysis with ATLAS.ti* by Susanne Friese (2014).

The two sets of data were coded based on the 11 concepts developed through the group concept mapping efforts. Once all of the statements were coded, analyses were performed and the results were compared to those from the group concept mapping exercises. These two sets of data were analyzed independently for content and compared to the group concept mapping results in order to compare the competencies defined by the expert team science managers with the competencies that the position descriptions and announcements identified. Two techniques were utilized: quantitative analysis through word and phrase counts and qualitative analysis of phrases that were mapped back to the original GCM ideas and concepts.

Content Analysis: Reliability and Validity

To address issues of validity, the expert advisory group met after the data was collected and the first round of analyses were conducted in order to engage in a focused conversation and review these preliminary findings. The advisory team was asked to make sound judgments based on their extensive experience as team science managers and review the coding results. By using the group concept mapping results as the codes for the content analysis section, the researcher was able to compare the findings from each research method to determine if there was a difference between the competencies defined by the experts and those being identified through recent team science-related position descriptions. The population that was depicted in the final data sets, 147 nation-wide and 24 EPSCoR position description and announcement documents, reflected a wide range of positions from across the country and allowed for a rich description and a level of confidence that the results were transferable to programs outside of the specific institutions and positions represented in each document.

Chapter 4 Results

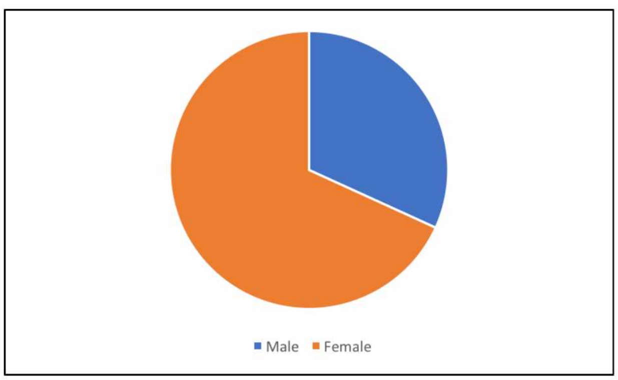
Introduction

The purpose of this section is to present both the quantitative and qualitative findings of this study to define what competencies are required to be an effective team science manager. The results of this project are best examined in two steps, the first summarizes the findings from Group Concept Mapping and the second summarizes the content analysis of the body of documents collected for this research.

Group Concept Mapping

Demographics

Demographics were collected for those who participated in the Group Concept Mapping brainstorming session. Of the 22 total participants, 15 were female and 7 were male; 7 identified themselves as faculty and 15 as staff (Figure 5).



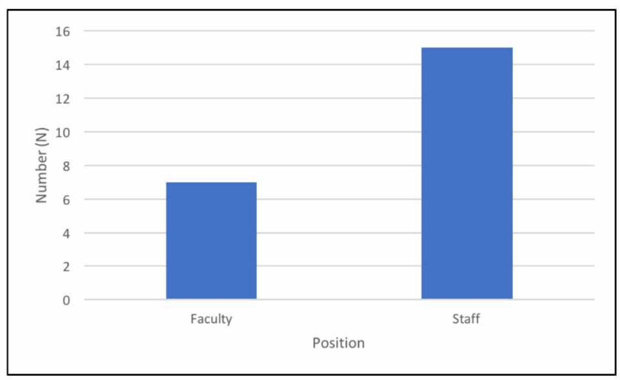


Figure 5. Demographics (gender and position) of the group concept mapping participants.

When asked about the length of time they had been involved with managing large interdisciplinary team science projects, 9 indicated they had 2-5 years, 7 had 6-10 years and 6 had 11-15 years of experience (Figure 6).

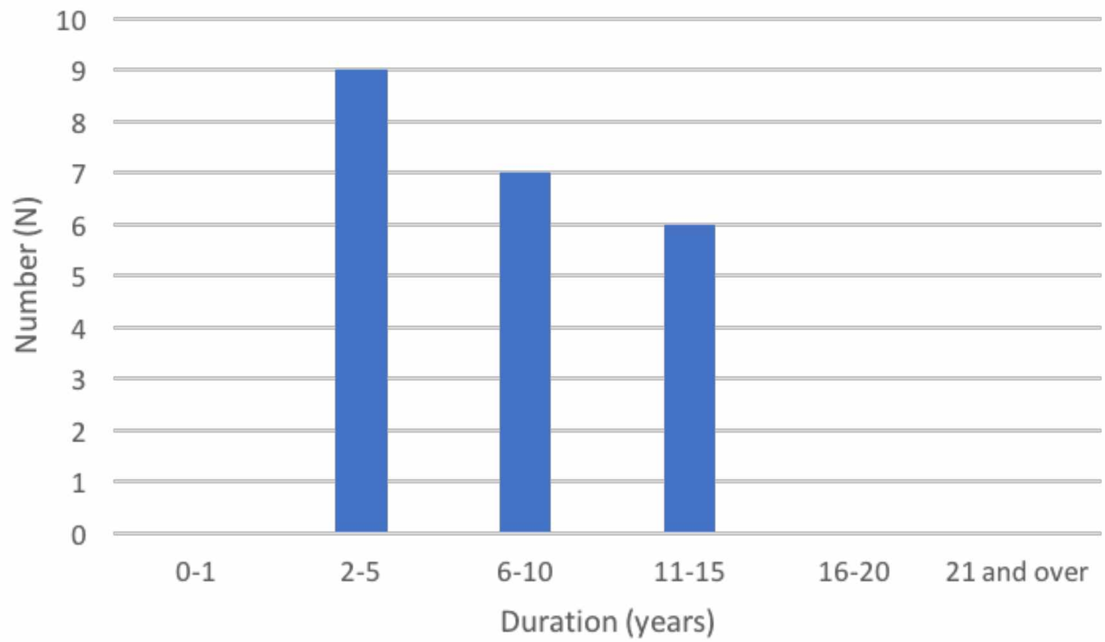


Figure 6. Plot of length of time in management position for group concept mapping participants.

The group also identified themselves as being comprised of 13 project administrators; 4 project directors; 1 principal investigator; 3 education, outreach and diversity managers; and 1 communication specialist, categories in which participants in EPSCoR leadership roles typically identify (Figure 7).

Point and Cluster Maps

The brainstorming session resulted in 120 statements (see Appendix D) that represented the group's ideas about what an effective team science manager needs to be able to know or to do. Sorting statements into clusters can be done manually using paper or index cards, but CS Global MAX provides a dropdown menu for sorting in the online research site (Figure 8).

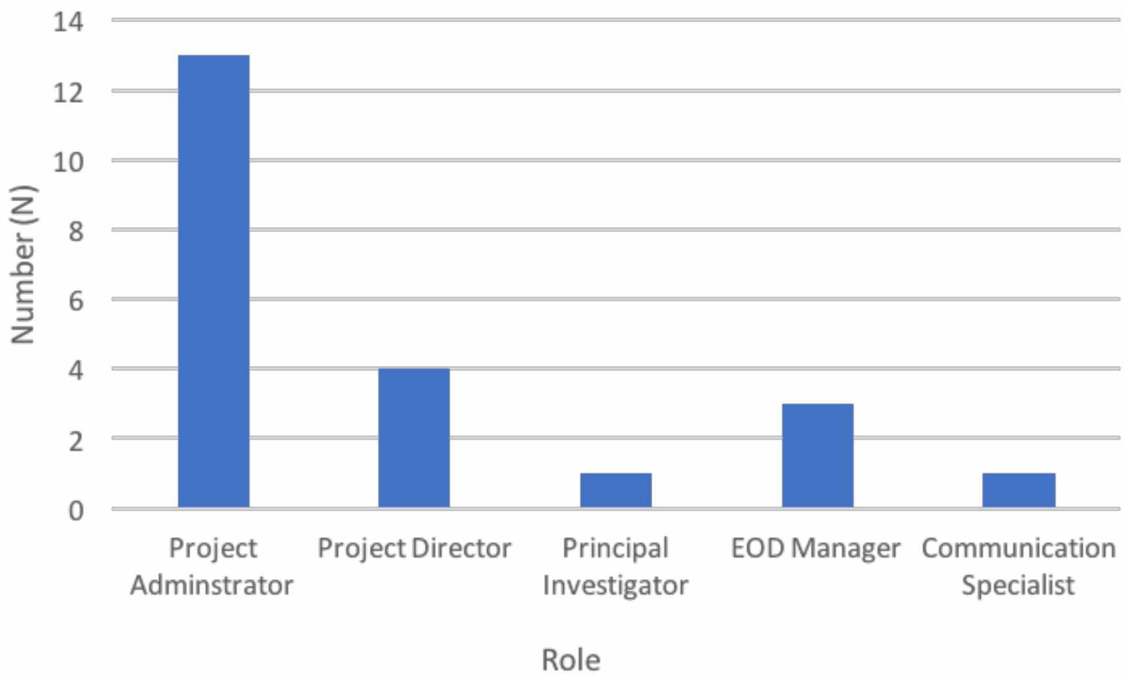


Figure 7. Plot of position types for group concept mapping participant.

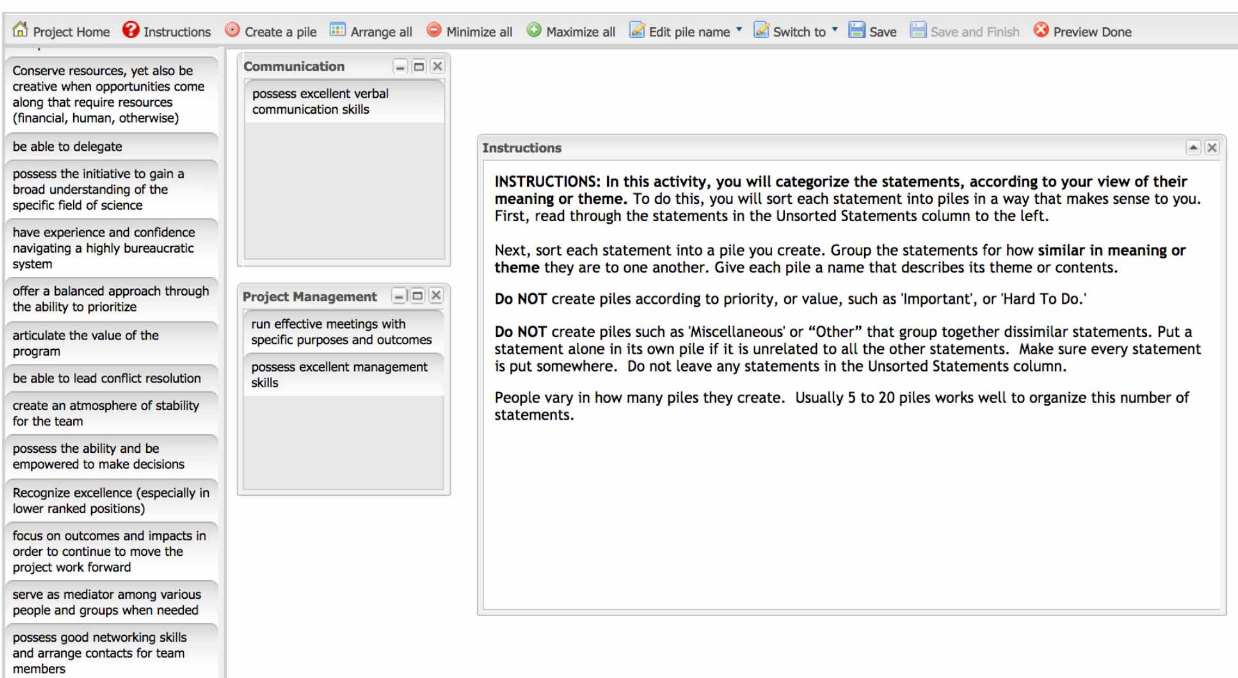


Figure 8. Screen shot of CS Global MAX software that allows participants to sort statements into concept groups using a dropdown menu.

The statements were sorted into concepts by each participant, resulting in a single 120x120 matrix for each person with identical cells on the top right and lower left halves (Table 2).

Table 2. Screen shot of the matrix that resulted from one participant sorting all 120 statements. The first 15 statements are included as an example. "0" denotes statements were not sorted into the same group; "1" denotes statements were sorted into the same group.

Statement	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15 …**	**120**
1		0	0	0	0	0	1	1	0	0	0	1	1	0	0	0
2	0		0	1	0	0	0	0	0	1	0	0	0	0	0	1
3	0	0		0	1	0	0	0	0	0	0	0	0	0	0	0
4	0	1	0		0	0	0	0	0	1	0	0	0	0	0	1
5	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0		0	0	1	0	0	0	0	0	1	0
7	1	0	0	0	0	0		1	0	0	0	1	1	0	0	0
8	1	0	0	0	0	0	1		0	0	0	1	1	0	0	0
9	0	0	0	0	0	1	0	0		0	0	0	0	0	1	0
10	0	1	0	1	0	0	0	0	0		0	0	0	0	0	1
11	0	0	0	0	0	0	0	0	0	0		0	0	1	0	0
12	1	0	0	0	0	0	1	1	0	0	0		1	0	0	0
13	1	0	0	0	0	0	1	1	0	0	0	1		0	0	0
14	0	0	0	0	0	0	0	0	0	0	1	0	0		0	0
15	0	0	0	0	0	1	0	0	1	0	0	0	0	0		0
…																
120	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	

Once the sorting was completed, the 22 matrices were combined to create a single similarity matrix that shows the number of participants who sorted each pair of statements together in the sorting exercise (Table 3). The final similarity matrix is provided in Appendix E. Multi-dimensional scaling of the similarity matrix was used to locate each statement as an individual point on a two-dimensional (x,y) plot, otherwise known as the point map (Figure 9).

The map shows the relative relationship of each idea with every other idea. Points that are positioned in close proximity on the map indicate many participants sorted them into the

Table 3. A screen shot of the similarity matrix that includes a summary of all participant sorting information. The first 15 statements are included as an example.

Statement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 …	120
1		5	7	5	9	7	8	5	5	4	6	3	7	5	5	2
2	5		2	14	1	9	8	7	0	15	0	4	7	0	0	15
3	7	2		4	9	3	2	5	3	2	8	2	9	5	6	3
4	5	14	4		2	14	11	10	1	13	1	8	7	1	1	10
5	9	1	9	2		3	2	4	8	1	8	0	5	11	7	1
6	7	9	3	14	3		9	7	6	8	1	6	6	1	4	7
7	8	8	2	11	2	9		9	2	9	1	10	7	1	2	7
8	5	7	5	10	4	7	9		4	8	2	10	9	2	2	6
9	5	0	3	1	8	6	2	4		2	5	1	2	3	14	1
10	4	15	2	13	1	8	9	8	2		0	8	6	0	0	13
11	6	0	8	1	8	1	1	2	5	0		0	6	7	6	0
12	3	4	2	8	0	6	10	10	1	8	0		5	0	0	5
13	7	7	9	7	5	6	7	9	2	6	6	5		2	3	8
14	5	0	5	1	11	1	1	2	3	0	7	0	2		7	0
15	5	0	6	1	7	4	2	2	14	0	6	0	3	7		0
…																
120	2	15	3	10	1	7	7	6	1	13	0	5	8	0	0	

same conceptual group. However, points that are located farther apart from each other were rarely sorted into the same conceptual group. A stress value of 0.26 was calculated for the map, indicating that the results are considered reliable within typical tolerances defined for this methodology. Point maps provide the underlying structure of subsequent concept maps.

A hierarchical cluster analysis was performed to partition the points (statements) on the map into groups of statements that aggregate to reflect similar concepts. A succession of 12 maps was developed to show the mathematical groupings of ideas into a successively smaller number of groups. These maps ranged from a total of 12 to 5 concept groups (see Figure 10 that includes eight of these maps) and provided the structure for the researcher to examine the statements within each group on each map.

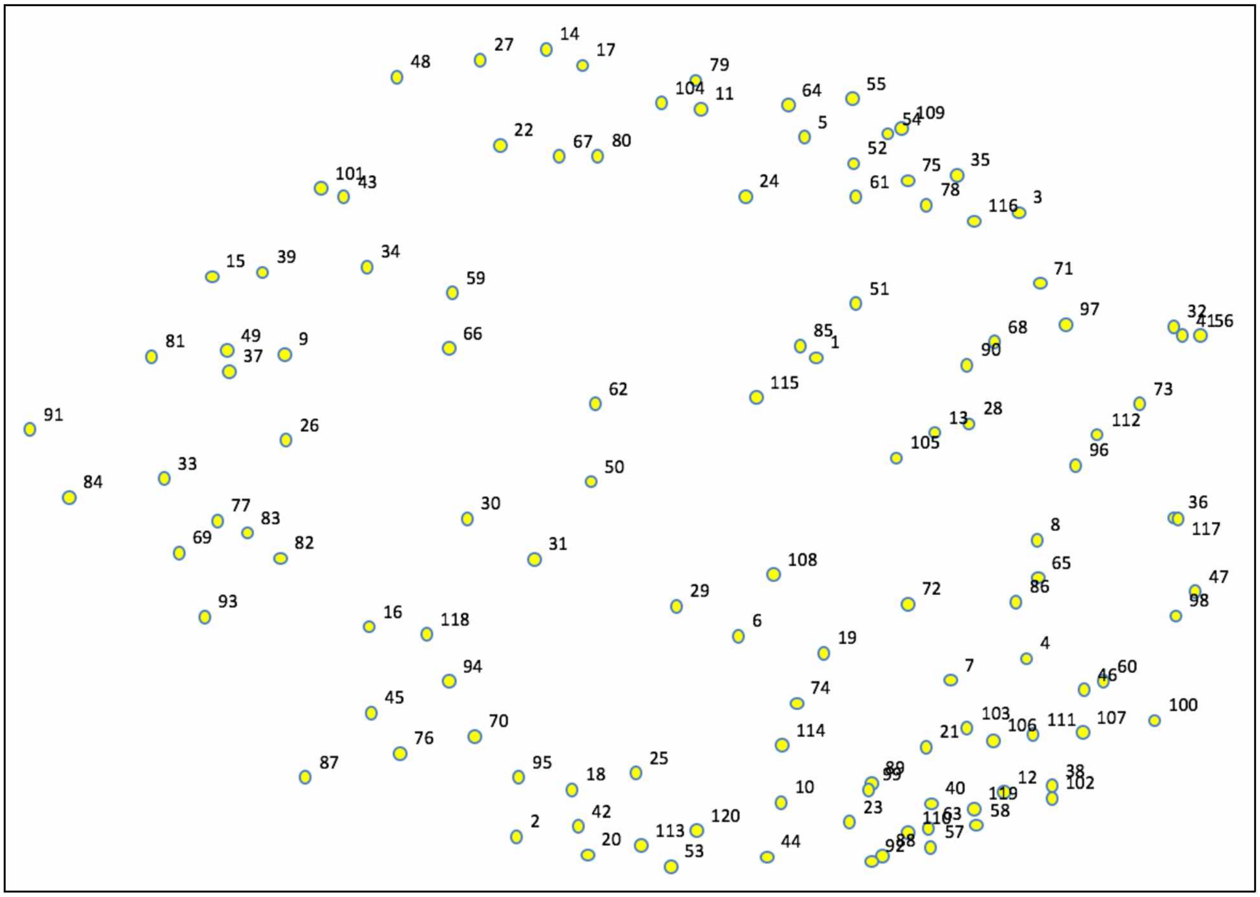


Figure 9. Point map representing the relationship of every statement to every other statement. Each dot represents one of the 120 statements from the group concept mapping exercise.

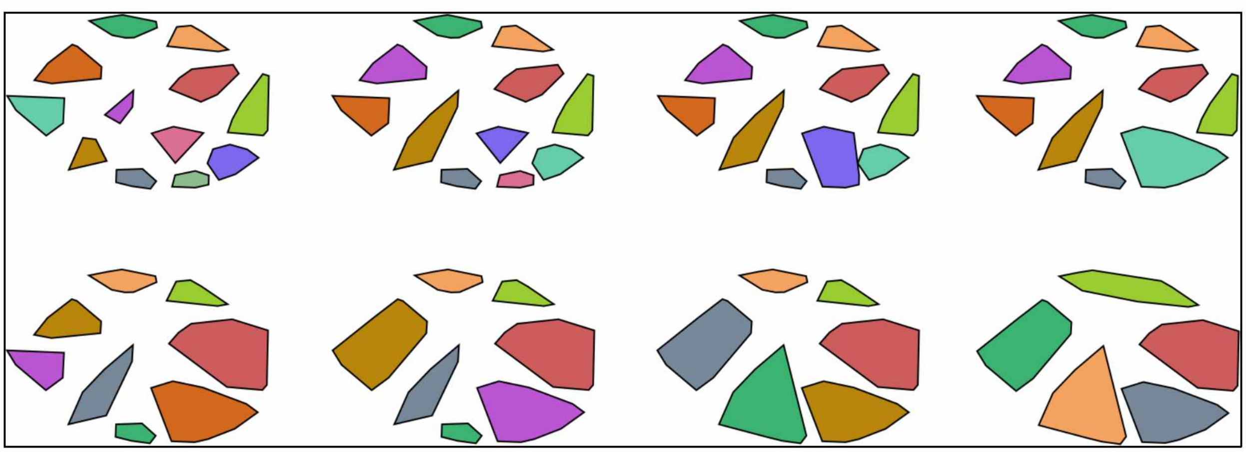
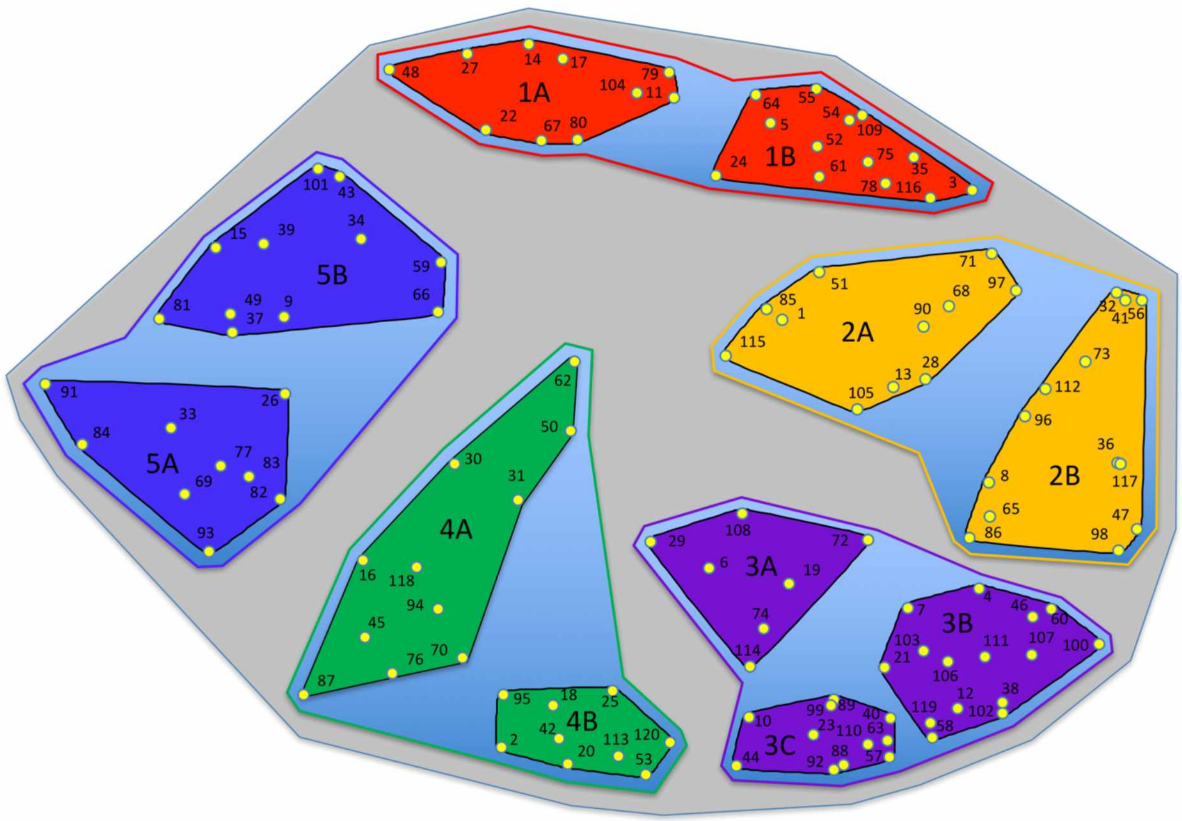


Figure 10. Cluster replay maps illustrate the successive groupings of concepts, in this case identifying the stepwise nature of mathematical groupings from a total of 12 to 5 concepts.

The maps in this figure do not include the points themselves but serve to illustrate the mechanism by which the points aggregate in a stepwise manner into fewer and fewer concept groups. This exercise was undertaken in order to determine the structure that best reflected the group concept mapping information. Close study of the maps and a thorough examination of the statements that appeared in each group on each map led the researcher to conclude that a concept map with five or six primary groups and 11 sub-categories would communicate the information most effectively with the right level of granularity in detail.

The advisory team deliberated and ultimately confirmed that five major categories and 11 sub-categories best described the ideas constructed by the EPSCoR participants (Figure 11). Titles that best reflected the ideas within each group were developed by the principal researcher in consultation with the advisory team. After significant discussion about the statements and how to best capture the essence of the ideas within each group, the following titles were agreed to represent the final concept map: project management (knowing and doing); shared leadership (organizational management and organizational empowerment); personal competence (team management, self-management and self-awareness); social competence (relationship management and social awareness) and communication (internal and external to the team). The final group concept map is the foundation for understanding the competencies required of effective team science managers and has ramifications for future planning and evaluation of professional development programs, setting priorities for the field, creating logic models and road maps, and more.

Just as the distance between points signifies a degree of similarity, so do the distances between clusters. The upper section of the map relates to program management skills while the



1. Project Management: A. Knowing B. Doing
2. Shared Leadership: A. Organizational Management B. Organizational Empowerment
3. Personal Competence: A. Team Management B. Self-management C. Self-awareness
4. Social Competence: A. Relationship Management B. Social Awareness
5. Communication: A. Internal to Team B. External to Team

Figure 11. Final clusters that represent the concepts that emerged in the group concept mapping exercise and define the competencies required for effective team science managers.

lower section speaks to personal and social competencies. The left section is all about communication while the right side reflects ideas about a shared leadership approach, a common approach to leading and managing large, interdisciplinary science teams. A handful of statements could have fit in a conceptual group adjacent to their location as determined through multivariate analysis and hierarchical clustering. The researcher and advisory team members made the decision to leave all points in their mathematically determined clusters and explain the subtle variations in meanings between statements within the concept group by agreeing that conceptual group titles are general in nature and refer to the essence of the ideas within each group.

Once the final concept map was confirmed by the advisory team, definitions for each of the clusters were developed by the researcher as the basis for a final discussion with the team. Due to the extensive conversations about the appropriate level of cluster granularity and the detailed deliberations about each statement, giving definitions to the clusters was relatively easy. The team quickly came to agreement and confirmed the final definitions of each cluster (Figure 12). Table 4 lists five statements in each sub-category that define the essence of the group. Each sub-category was defined by up to 15 statements that broadly defined the concept group, and as stated previously, statements that could fit into several different clusters were left in their mathematical home as calculated by the multivariate analysis.

Points

Participants rated each statement for feasibility on a Likert scale of 1 to 5 to identify which specific competencies were more or less feasible to require of a team science manager. The average ratings of feasibility for each point ranged from 3.33 to 4.72 with the highest feasibility ratings emerging in the following six competencies: two points (3 and 5) in project management – doing; three points (51, 97, and 115) in shared leadership - organizational management; three points (47, 56 and 117) in shared leadership – organizational empowerment, one point (7) in personal competence - team management, one point (110) in personal competence - self-awareness, and three points (2, 53 and 113) in social competence - social awareness (Figure 13).

Project management is the application (*doing*) of knowledge, skills, tools (*knowing*), and techniques to project activities to meet the project requirements.

Shared leadership is a leadership style that broadly distributes leadership responsibility, such that people within a team and organization lead each other.

The contextual circumstances of a particular team might require shared leadership, in which leaders share leadership roles, functions, and behaviors among team members. Shared leadership can be formally appointed at the outset ...or can emerge (Mann, 1959; Judge et al., 2002).

Organizational management is the process of organizing, planning, leading and controlling resources within an entity with the overall aim of achieving its objectives.

The organizational management must make decisions and resolve issues to be effective and beneficial.

Organizational empowerment is the process of empowering employees in an ongoing process of providing the tools, training, resources, encouragement and motivation workers need to perform at the optimum level.

Empowerment is the process of enabling individuals to adopt new behaviors that further their individual aspirations and those of their organizations.

Personal Competence

Team management is the ability of an individual (or an organization) to administer and coordinate a group of individuals to perform a task.

Self-management builds on self-awareness, using own self-control to ensure that emotions don't control you regardless of the situation (Goleman, 2005)

Self-awareness means that you understand how you feel and can accurately assess your own emotional state. Competencies: • Emotional self-awareness • Accurate self-assessment • Self-confidence

*Self-awareness i*s your ability to recognize your own emotions and their effects on yourself and other people (Goleman, 2005)

It represents the foundation of emotional intelligence because without being aware of and understanding your own emotions it is impossible to move into the other competencies like self-management and social awareness.

Social Competence (Goleman, 2005)

Relationship management involves clear communication and effective handling of conflict.

It is the bond you build with others over time. You need to be able to see the benefit of connecting with many different people, even those you are not so fond of.

Social awareness means you carefully consider what people want, and plan to communicate with them in a way that is intended to meet that need.

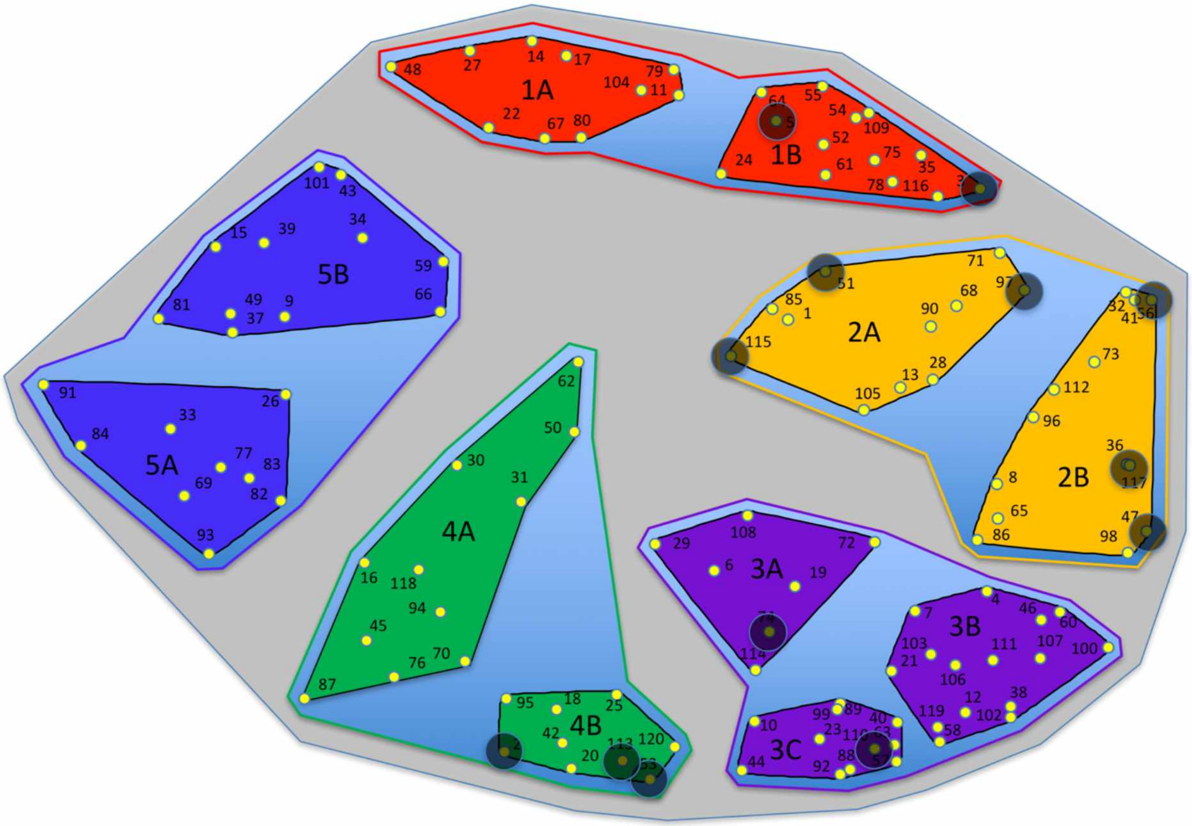
Competencies: Empathy - understanding the other person's emotions, needs and concerns. Organizational Awareness - the ability to understand the politics within an organization and how these affect the people working in them, and Service - the ability to understand and meet the needs of clients and customers.

Communication *(internal to the team* and *external* between the team and the rest of the world**)** is the imparting or exchanging of information or news, a two-way process of reaching mutual understanding.

Figure 12. Definitions of Group Concept Mapping concept headings.

Table 4. List of statements that best reflect the meaning of each of the 11 clusters.

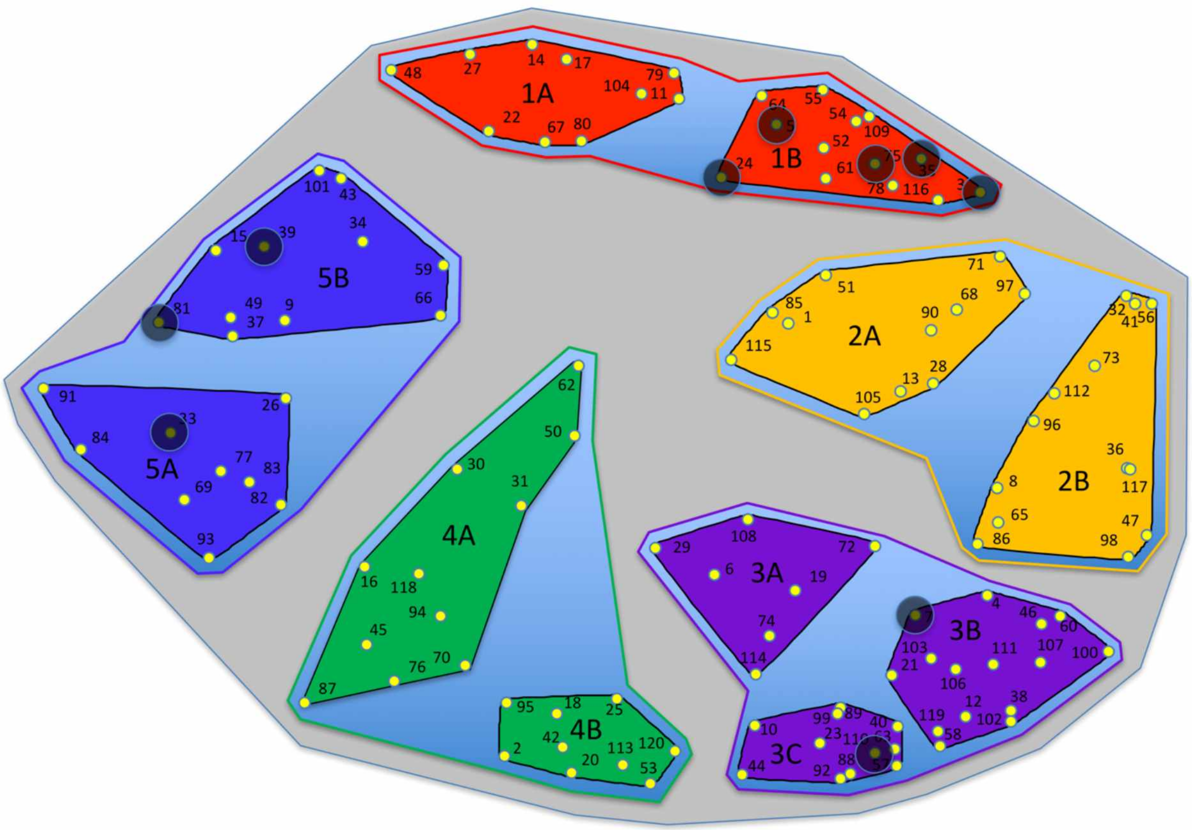
Point #	Custer	Statement
22	1A	have a good understanding of academic culture
67	1A	have experience and confidence navigating a highly bureaucratic system
79	1A	understand creative budgeting and flexible management in order to attain goals of the program
48	1A	understand federal, state and university policies and know where to get help and information
27	1A	understand how to develop complex budgets within an academic institution
35	1B	be able to manage complex competing demands and deadlines
64	1B	conserve resources, yet also be creative when opportunities come along that require resources (financial, human,
54	1B	design and implement systems to standardize processes of the team
109	1B	develop systems to track team progress
24	1B	run effective meetings with specific purposes and outcomes
105	2A	be adept at personnel management
28	2A	know when to use carrots and sticks to keep everything on track; employ tact and display toughness when necessary
68	2A	offer a balanced approach through the ability to prioritize
115	2A	see and understand the whole picture
85	2A	understand the strengths and weaknesses of the team and how to use that as a strategic advantage
36	2B	be able to deal with change - be agile with shifting landscapes
56	2B	be organized
8	2B	do not micromanage
112	2B	manage responsibilities without a lot of power
73	2B	possess the ability and be empowered to make decisions
6	3A	convey that you genuinely believe in the mission of the team
72	3A	create an atmosphere of stability for the team
19	3A	instill confidence within team members and support people even if they have a different idea of how to accomplish programmatic goals
74	3A	recognize excellence (especially in lower ranked positions)
114	3A	serve as a mentor
106	3B	accept criticism and use the information to promote positive change
46	3B	be the person who looks at opportunities and solutions, not problems and barriers
119	3B	exhibit a sense of calm and self-efficacy
107	3B	identify strengths and weaknesses in yourself as a leader
103	3B	practice transparency in order to instill trust
99	3C	be able to establish trust
63	3C	be open-minded
88	3C	be positive and optimistic
23	3C	put ego aside for the sake of the team
110	3C	show respect to all
118	4A	act as a liaison between numerous parties depending on situation
87	4A	act as an arbitrator in dealing with different people
45	4A	create a safe environment for people to share thoughts and ideas
50	4A	help create a common language for team members
30	4A	know how to work with diverse populations of researchers and staff
113	4B	be a good active listener
18	4B	be able to deal with difficult people
53	4B	be calm, be diplomatic and be respectful
25	4B	be sensitive to and aware of team dynamics
120	4B	identify talent and acknowledge the work of others
82	5A	be a team player and be able to articulate the benefits and costs of team science
84	5A	be able to converse with many different kinds of collaborators and partners
93	5A	be able to help the team connect the dots by seeing the big picture
83	5A	communicate a clear vision
33	5A	possess excellent verbal communication skills
81	5B	possess good writing skills
66	5B	possess the initiative to gain a broad understanding of the specific field of science
9	5B	understand and be able to articulate the goals of the project in the larger context of broader impacts
43	5B	understand the strategic missions and priorities of the institution, state and federal government, and funding agency to frame the work of the team
34	5B	work with upper administrators to get support and understanding



1. Project Management: A. Knowing B. Doing
2. Shared Leadership: A. Organizational Management B. Organizational Empowerment
3. Personal Competence: A. Team Management B. Self-management C. Self-awareness
4. Social Competence: A. Relationship Management B. Social Awareness
5. Communication: A. Internal to Team B. External to Team

Figure 13. Points map that identifies the points (grey circles) with the highest ratings of feasibility.

Participants also rated each statement for importance on a Likert scale of 1 to 5 to identify which specific competencies are more or less important to require of a team science manager. The average ratings of importance for each point ranged from 3.28 to 4.72 with the highest importance ratings emerging in the following five competencies: five points (3, 5, 24, 35, and 75) in project management – doing; one point (7) in personal competence – self-management, one point (110) in personal management – self-awareness, one point (33) in communication – internal; and two points (39 and 81) in communication – external (Figure 14).



1. Project Management: A. Knowing B. Doing
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3. Personal Competence: A. Team Management B. Self-management C. Self-awareness
4. Social Competence: A. Relationship Management B. Social Awareness
5. Communication: A. Internal to Team B. External to Team

Figure 14. Points map that identifies the points (grey circles) with the highest ratings of importance.

A spanning analysis was performed on the data to determine which points served as bridges and which served as anchors. A point with a relatively high bridging value (bridge point) indicated that the idea was sorted by the research participants with many other points across the map and identified as a link, or bridging idea. However, a point with a relatively low bridging value (anchor point) reflected well the content in the near vicinity but did not connect ideas between different concept groups. Whether a point appears to more closely resemble an anchor or a bridge can provide insight into the areas of the map as well as the relationships among areas on the map. A diagram of two points, one with high and the other with low bridging values, is provided in Figures 15 and 16 to illustrate the differences.

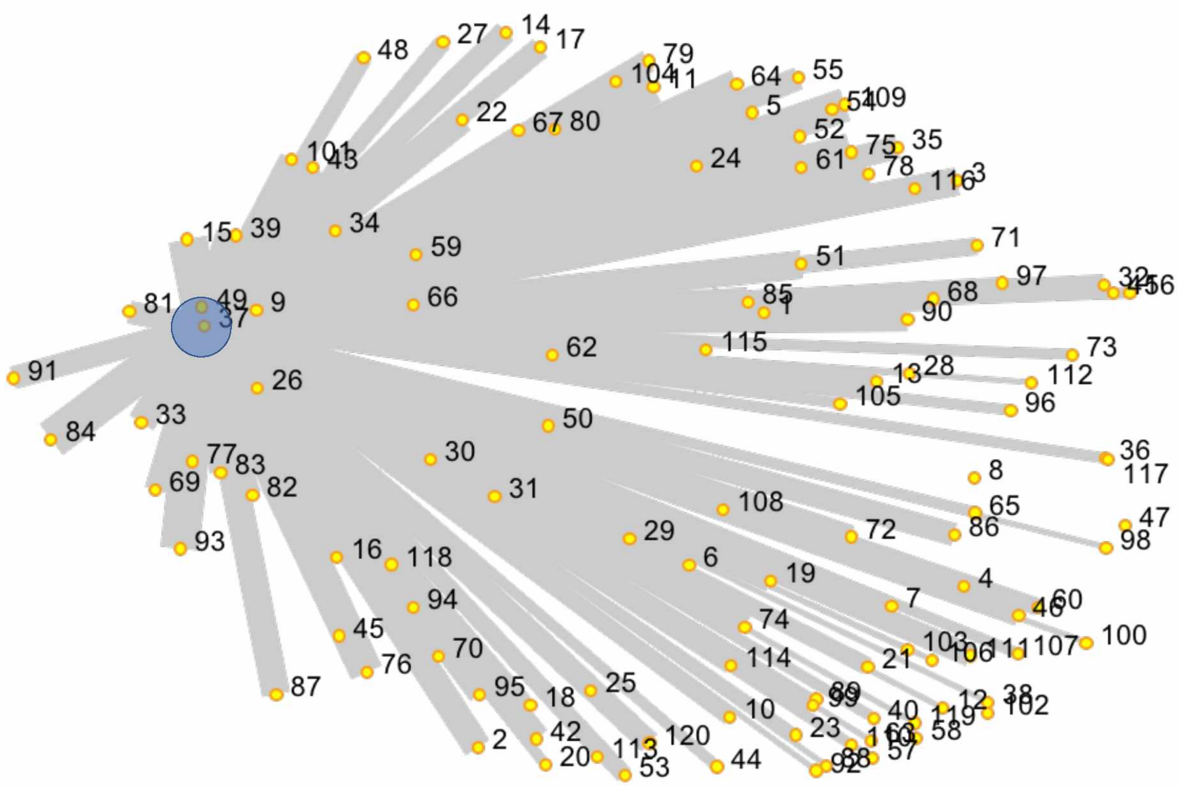


Figure 15. Spanning analysis for a bridge point (37) with a high spanning value of 0.93. Grey lines between points represent the number of times each pair of points were grouped together. The wider the line, the more people grouped the pair. Statement 37 was sorted many times with many other statements.

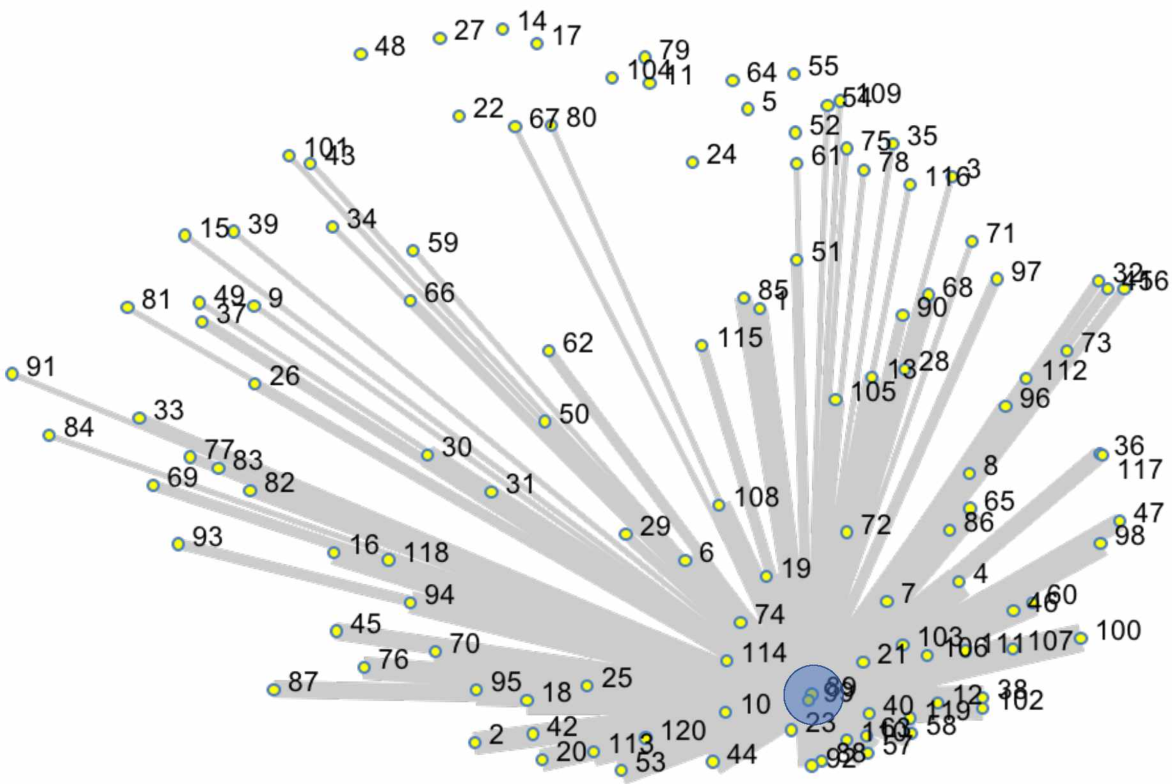
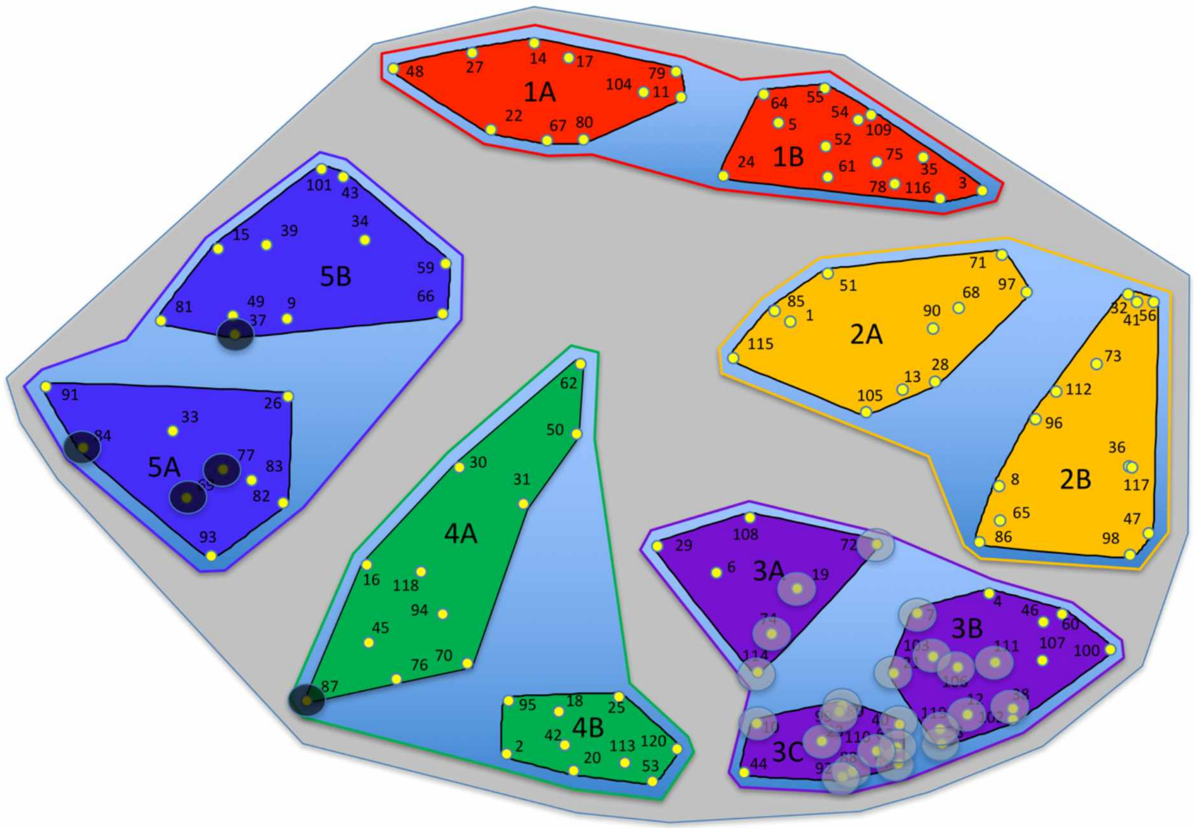


Figure 16. Spanning analysis for a bridge point (99) with a low spanning value of 0. Grey lines between points represent the number of times each pair of points were grouped together. The wider the line, the more people grouped the pair. Statement 99 was sorted with other ideas less frequently than most statements.

Figure 17 shows the bridging values for each point with dark grey circles indicating points with the highest bridging values (0.8-1.0) and light grey circles identifying those with the lowest bridging values (0-0.2). Of note is that points with bridging values in the range of 0.8 to 1.0 (bridge points) are concentrated within three conceptual groups: one point (87) in social competence – relationship management; three points (69, 77 and 84) in communication – internal; and one point (37) in communication – external. The 23 points within the range of 0 to 0.2 (anchor points) were clustered in three specific conceptual groups: four points (19, 72, 74 and 114) in personal



1. Project Management: A. Knowing B. Doing
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3. Personal Competence: A. Team Management B. Self-management C. Self-awareness
4. Social Competence: A. Relationship Management B. Social Awareness
5. Communication: A. Internal to Team B. External to Team

Figure 17. Point bridging map that identifies statements with high bridge values identified by dark grey circles and low bridge (or anchor) values identified by light grey circles. See Appendix F for a complete list of all point statistics.

competence – team management; nine points (7, 12, 21, 38, 58, 103, 106, 111, and 119) in personal competence – self-management; and 10 points (10, 23, 40, 57, 63, 88, 89, 92, 99 and 110) in personal competence – self-awareness.

Clusters

Average cluster ratings were calculated to determine which groups were most feasible to require of effective team science managers. Average cluster values for feasibility had a relatively small range (4.04 to 4.24) with social competence and personal competence rating the lowest, project management and communication rating the highest and shared leadership falling in the middle (Figure 18).

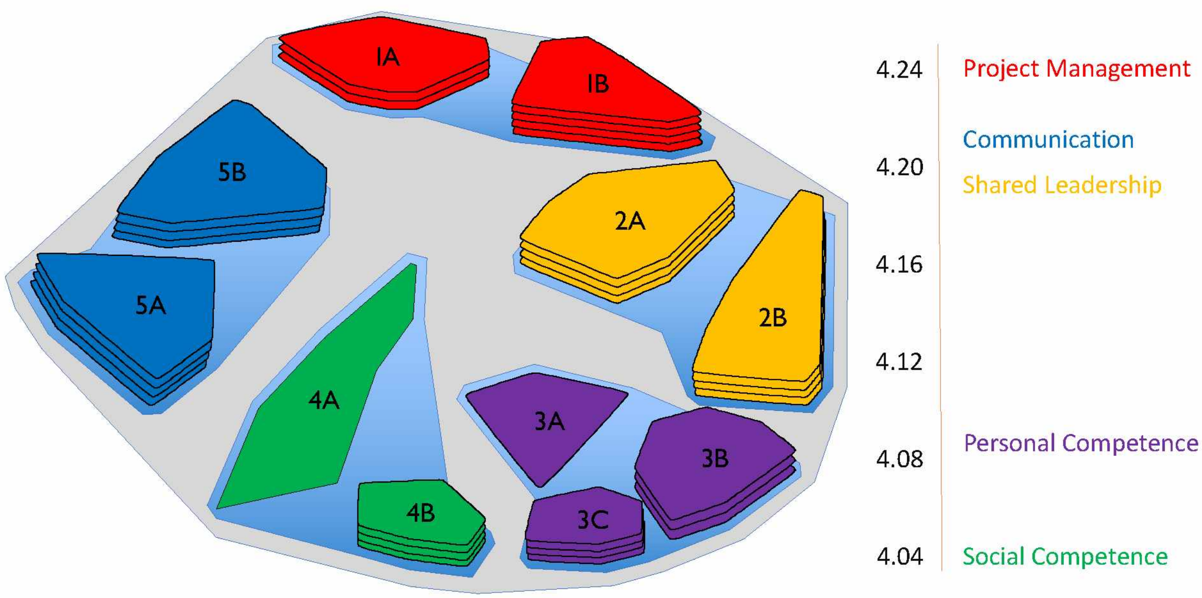

Figure 18. Cluster rating map with average cluster feasibility ratings represented by layers. Each layer represents a 0.04 step in rating on the Likert scale of 1 (not feasible) to 5 (very feasible).

Similar calculations were performed for the ratings of importance. These values ranged from 3.90 to 4.15 with social competence and personal competence again rating the lowest, project management and communication rating the highest and shared leadership falling in the middle (Figure 19).

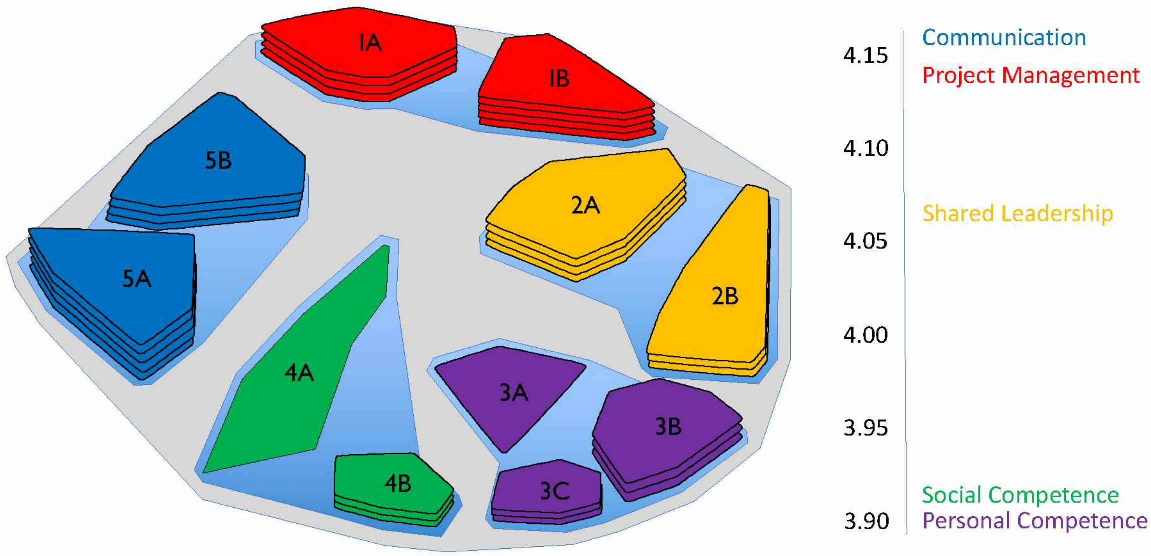

Figure 19. Cluster rating map with average cluster importance ratings represented by layers. Each layer represents a 0.05 step in rating on the Likert scale of 1 (not feasible) to 5 (very feasible).

Similar to the point bridging values, cluster bridging values are calculated to represent the connectedness of one cluster to the others. Bridging values ranged from 0.16 to 0.76 with low values for personal competence and project management and higher values for communication and social competence; shared leadership fell in the middle (Figure 20).

Pattern Matches and Go-Zones

Pattern matches provide a visual format for comparing the rating results from different groups of participants and illustrate how specific populations from the study think about team

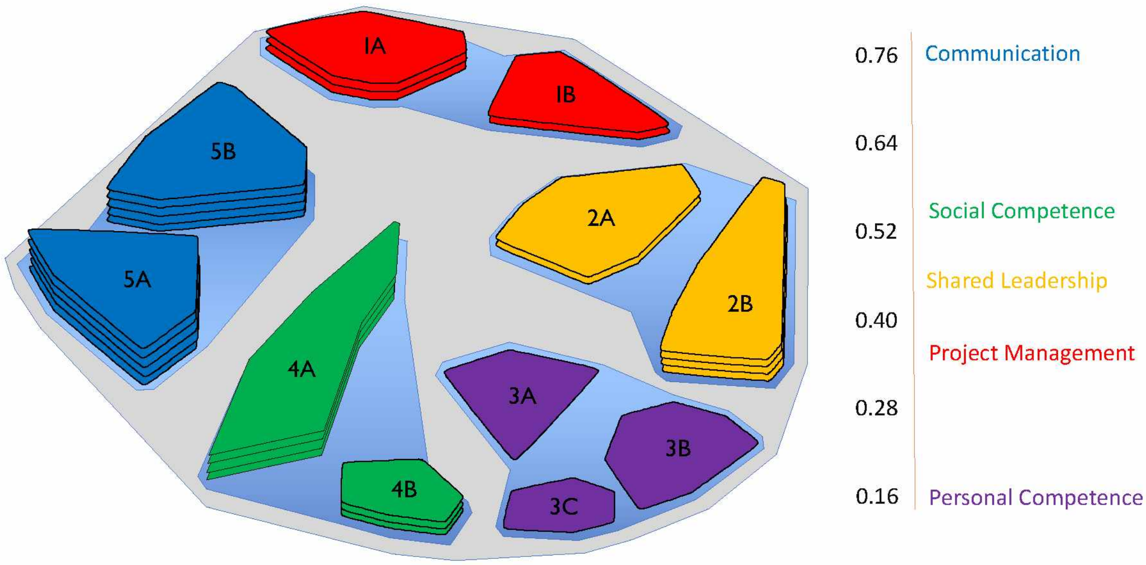

Figure 20. Cluster bridging map with average cluster bridging values represented by layers. Each layer represents a 0.12 step in bridging value.

science leadership competencies relative to one another. For comparative purposes, an absolute scale of 3.4 to 4.6 was used in each of the seven following figures. Absolute values for feasibility ratings tended to be lower for the more experienced (6-15 year) participants than for those with less experience (0-5 years), however the relative feasibility of each concept remained similar between the populations with two exceptions (Figure 21). More experienced project managers rated project management – doing somewhat more feasible and self-management somewhat less feasible than the less experienced project managers. There was a moderately strong correlation of r=0.66 between the two groups on the rating of feasibility.

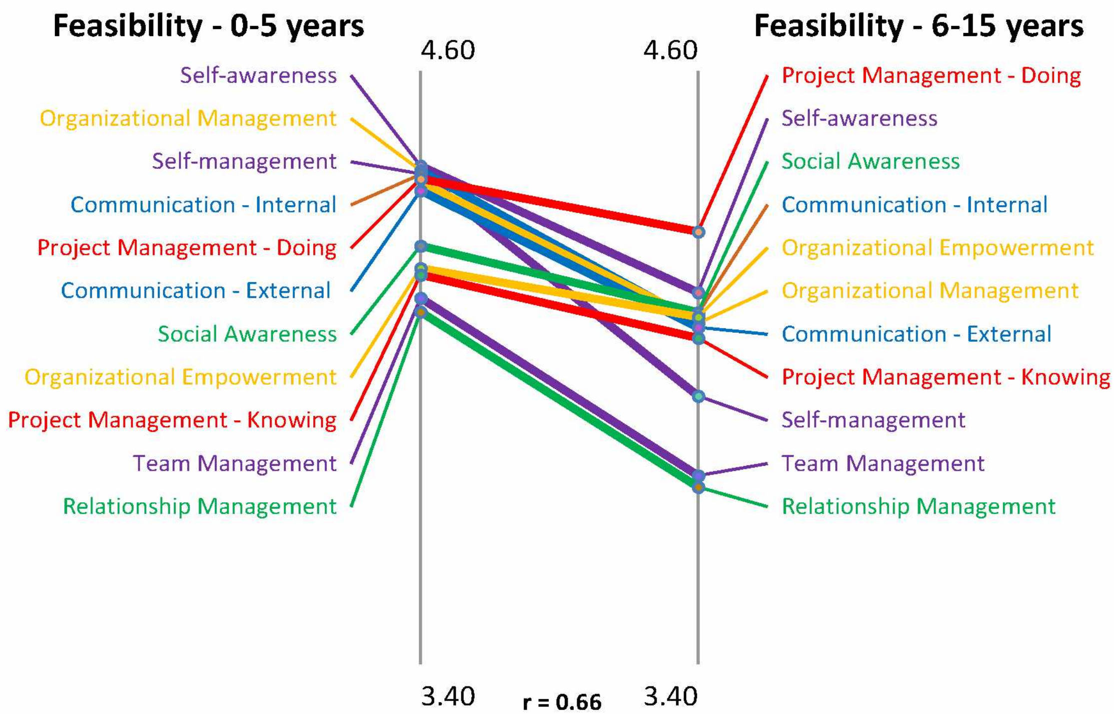

Figure 21. Pattern Match comparing feasibility ratings of each sub-concept between less (0-5 years) and more (6-15 years) experienced team science managers.

The pattern match based on gender indicates a slightly less clear differentiation of results than the above results for groups defined by longevity as project managers (Figure 22). While the range of values was relatively similar, males rated self-awareness and social awareness slightly more feasible than females. Females rated project management - doing, communication – external, communication – internal, organizational management, self-management, relationship management and team management slightly higher than the males. Two concepts, organizational empowerment and project management – knowing were rated most similarly feasible between males and females. There was a moderately strong correlation of r=0.60 between the two groups on the rating of feasibility.

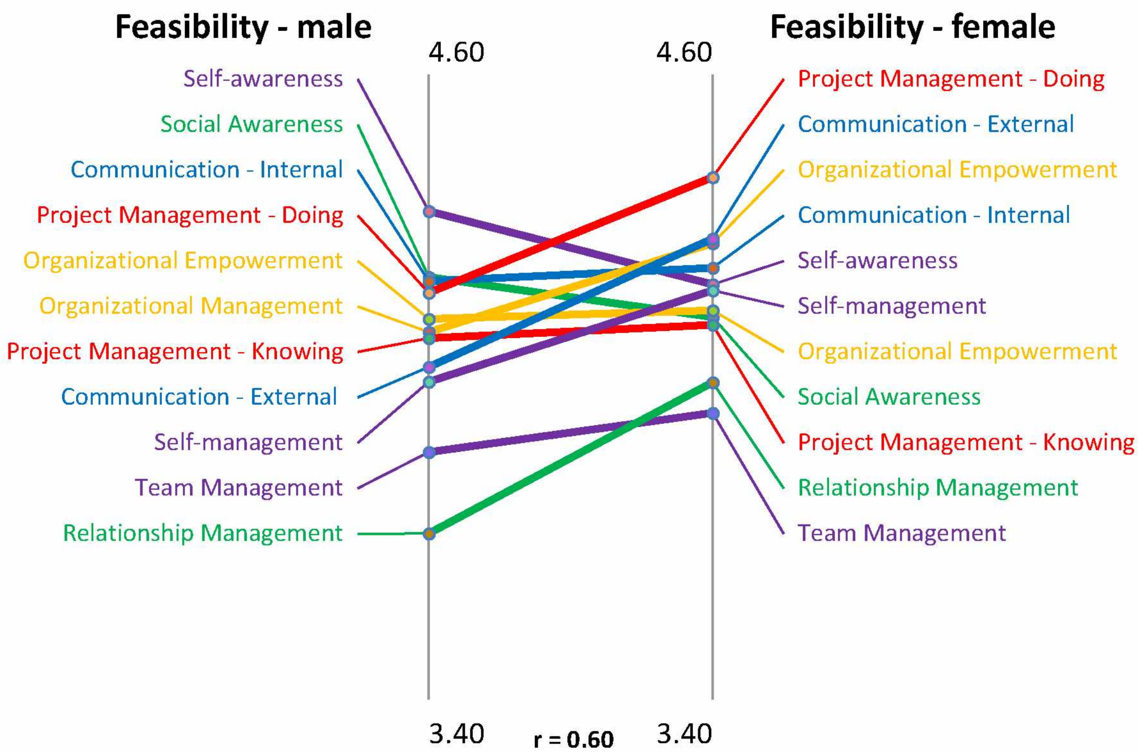

Figure 22. Pattern Match comparing feasibility ratings of each sub-concept between male and female team science managers.

When feasibility ratings for faculty are compared to those for staff a general trend emerges with faculty rating all concepts as more feasible than staff (Figure 23). Interestingly, most conceptual groups were relatively similar in importance with the exceptions that project management – doing and project management – knowing were rated slightly more feasible for the staff than faculty while self-management was rated slightly less feasible by staff than faculty. There was a moderately strong correlation of r=0.65 between the two groups on the rating of feasibility.

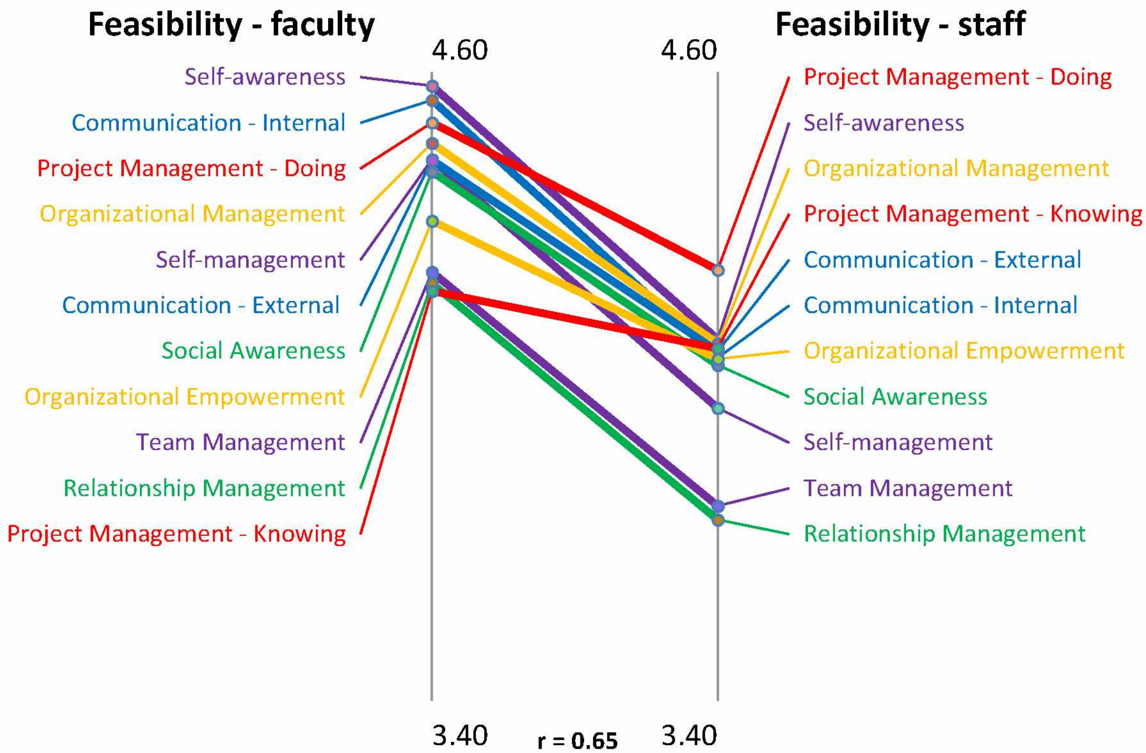

Figure 23. Pattern Match comparing feasibility ratings of each sub-concept between people who hold faculty and staff positions as team science managers.

The rating of importance was similarly evaluated across the same pairs of demographic groups. Differences in how participants rated the importance of the various competence groups based on their longevity in the role as project manager are illustrated in Figure 24. The range of values in importance ratings was larger than for the more experienced managers, and in general the less experienced mangers rated the importance of most competencies as more important than those with more experience. The exception to this is that the less experienced managers rated project management – doing as slightly less important and project management – knowing as similarly important compared to those with more experience. There was a moderately strong correlation of r=0.64 between the two groups on the rating of importance.

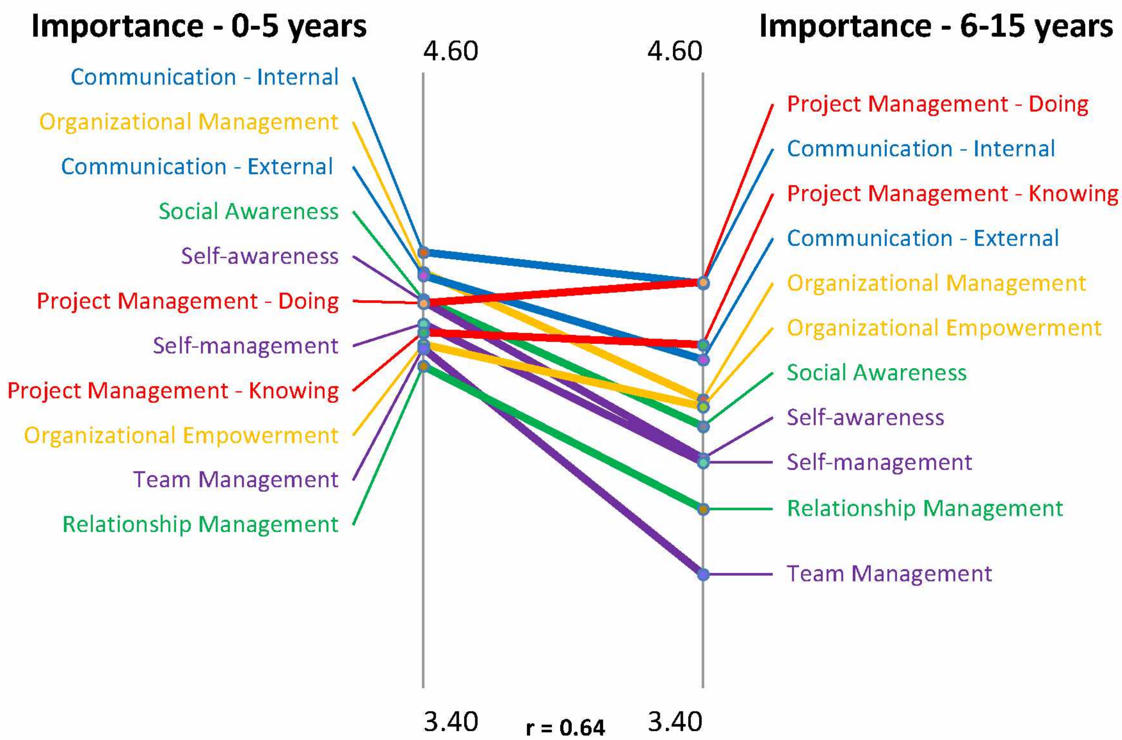

Figure 24. Pattern Match comparing importance ratings of each sub-concept between less (0-5 years) and more (6-15 years) experienced team science managers.

Ratings of importance based on gender indicate a pattern of females rating all competency categories higher in importance than males (Figure 25). Organizational management was rated lower in importance by males than females as compared to other competencies, however self-awareness was rated lower in importance by females as compared to other competencies. There was a strong correlation of r=0.71 between the two groups on the rating of importance.

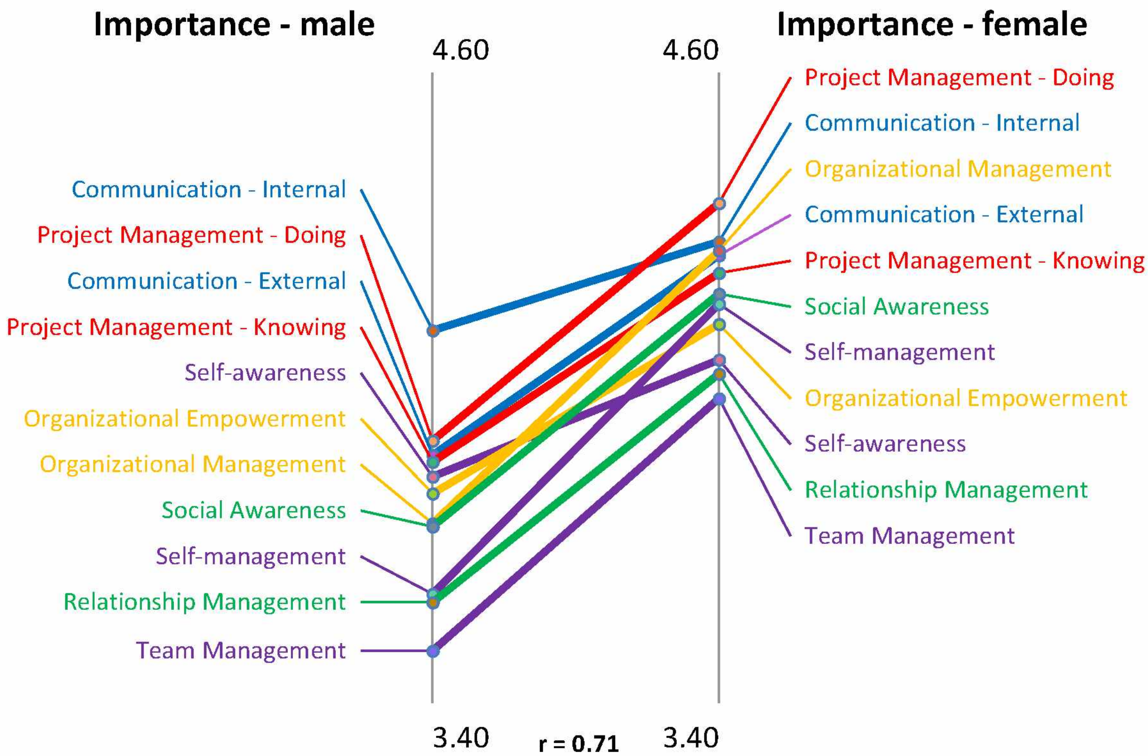

Figure 25. Pattern Match comparing importance ratings of each sub-concept between male and female team science managers.

Finally, faculty rated the importance of all competencies somewhat higher than their staff counterparts. Interestingly, competencies associated with team management, self-management, self-awareness, which together comprise the concept of personal competence showed the largest differences between the groups with faculty giving more importance to these categories than the staff did (Figure 26). Relationship management and social awareness which together comprise the concept of social competence, were rated relatively more important by the staff than the faculty. There was a moderately strong correlation of r=0.67 between the two groups on the rating of importance.

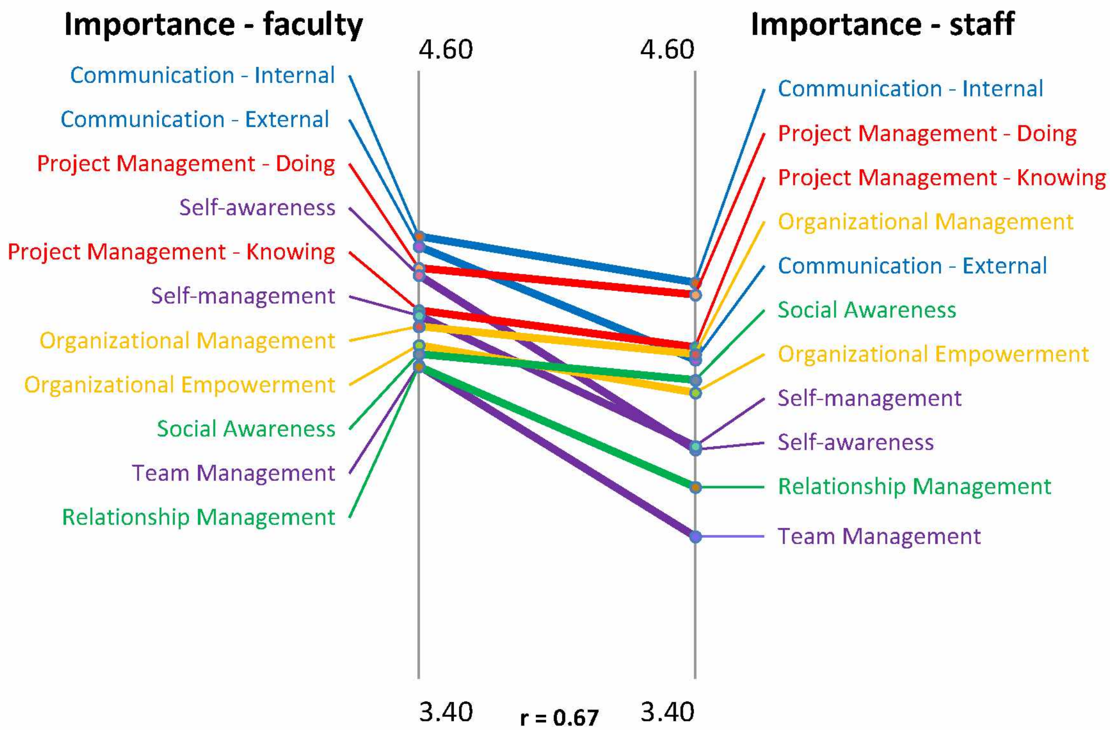

Figure 26. Pattern Match comparing importance ratings of each sub-concept between people who hold faculty and staff positions as team science managers.

Another means of presenting these findings to understand some of the more detailed nuances of participant ratings is through the use of a go-zone map (Figure 27) that compares feasibility versus importance for each idea on the point map. The upper right quadrant includes ideas (points) that are both most feasible and most important. The percentage of statements from each cluster that are found in the go-zone are summarized in Figure 28. While all except cluster 3A are represented in the go-zone, the largest percentage of statements in the go-zone are from clusters 1B, 2A and 5A. Go-zone statements are summarized in Table 5. As mentioned earlier and seen on this plot, ratings of feasibility range from 3.33 to 4.72; ratings of importance range from 3.28 to 4.72.

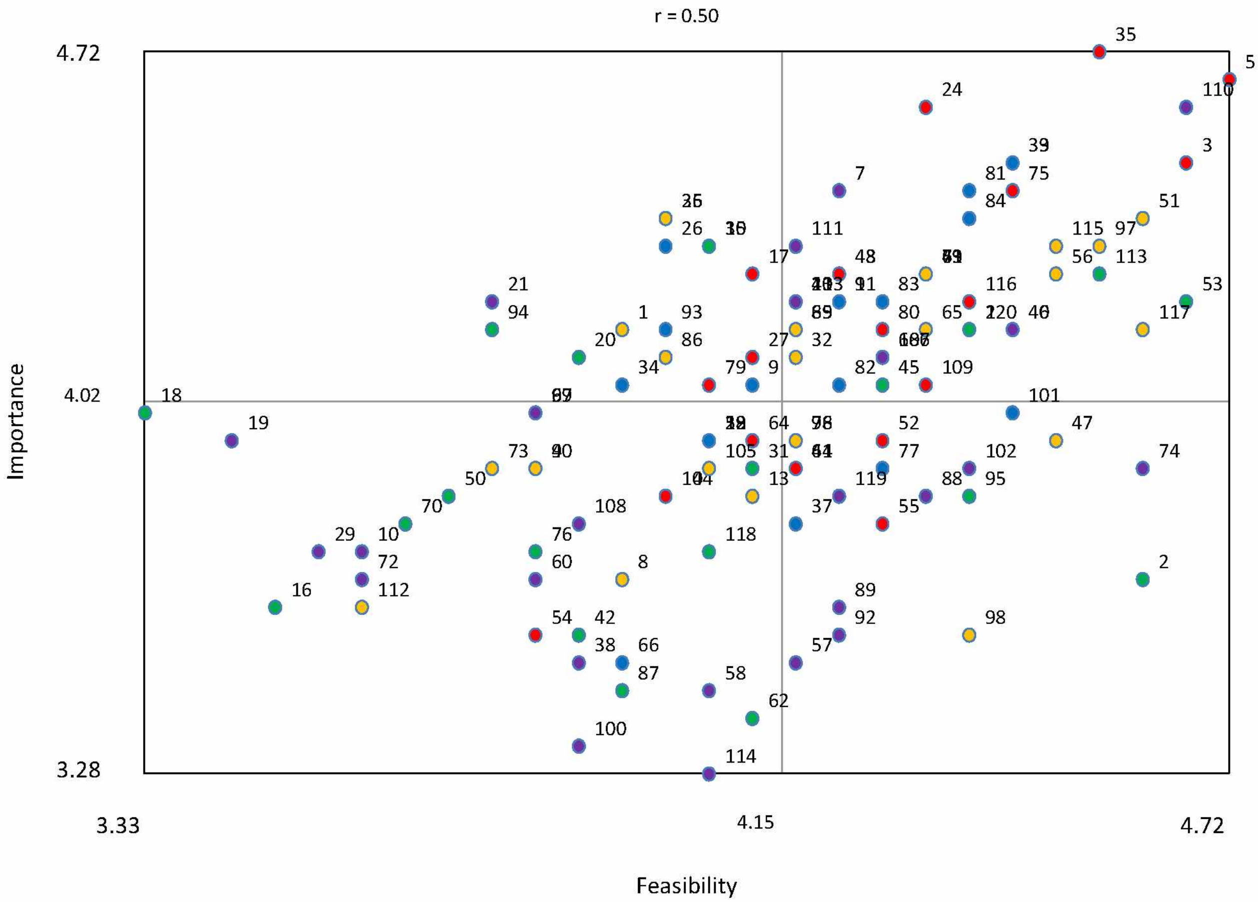

Figure 27. Go-zone plot of feasibility vs importance for each point (statement).

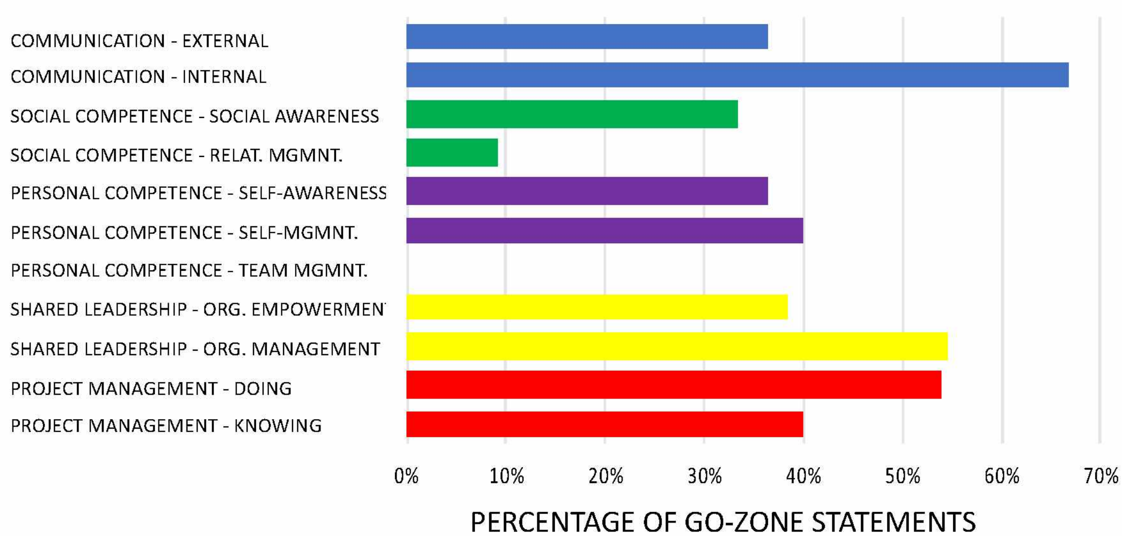

Figure 28. Percentage of statements in the go-zone for each cluster.

Table 5. List of go-zone statements and group numbers.

GROUP #	IDEA #	STATEMENT
1A	11	coordinate reporting, writing and presentations
1A	22	have a good understanding of academic culture
1A	48	understand federal, state and university policies and know where to get help and information
1A	80	leverage different sources of support
1B	3	ensure the follow-up on tasks assigned during leadership meetings; serve as a taskmaster when required
1B	5	have a clear understanding of project deliverables
1B	24	run effective meetings with specific purposes and outcomes
1B	35	be able to manage complex competing demands and deadlines
1B	75	focus on outcomes and impacts in order to continue to move the project work forward
1B	109	develop systems to track team progress
1B	116	do the homework and be prepared for every meeting and visit
2A	51	know the role and responsibilities of team members
2A	68	offer a balanced approach through the ability to prioritize
2A	71	possess excellent management skills
2A	85	understand the strengths and weaknesses of the team and how to use as a strategic advantage
2A	97	possess and promote good time management skills
2A	115	see and understand the whole picture
2B	32	be good at troubleshooting
2B	41	be detail-oriented
2B	56	be organized
2B	65	be able to delegate
2B	117	take ownership of the position
3B	7	be fair and consistent in decision making
3B	46	be the person who looks at opportunities and solutions, not problems and barriers.
3B	103	practice transparency in order to instill trust
3B	106	accept criticism and use the information to promote positive change
3B	107	identify strengths and weaknesses in yourself as a leader
3B	111	empower people to do things and then let them do it.
3C	23	put ego aside for the sake of the team
3C	40	admit mistakes, learn from them and move on
3C	63	be open-minded
3C	110	show respect to all
4A	45	create a safe environment for people to share thoughts and ideas
4B	53	be calm, be diplomatic and be respectful.
4B	113	be a good active listener
4B	120	identify talent and acknowledge the work of others
5A	33	possess excellent verbal communication skills
5A	69	articulate the value of the program
5A	82	be a team player and be able to articulate the benefits and costs of team science
5A	83	communicate a clear vision
5A	84	be able to converse with many different kinds of collaborators and partners

Content Analysis

The second phase of data analysis included content analysis of position descriptions and announcements of positions that had been posted over a period of years between 2010 and 2017. Of the 171 documents, 147 were associated with non-EPSCoR jurisdictions and 24 originated from one of the 31 EPSCoR jurisdictions. 2,176 quotes were analyzed from the first group; 533 quotes were analyzed from the second group. The summary of position types for the national positions indicates that the most prevalent jobs types were those associated with research development; second most prevalent were positions in research center leadership, sponsored programs and program leaders and/or managers. The remaining categories of federal and legislative affairs, grant support, program evaluation, and proposal developer were less prevalent but did add to the overall pool of documents (Figure 29).

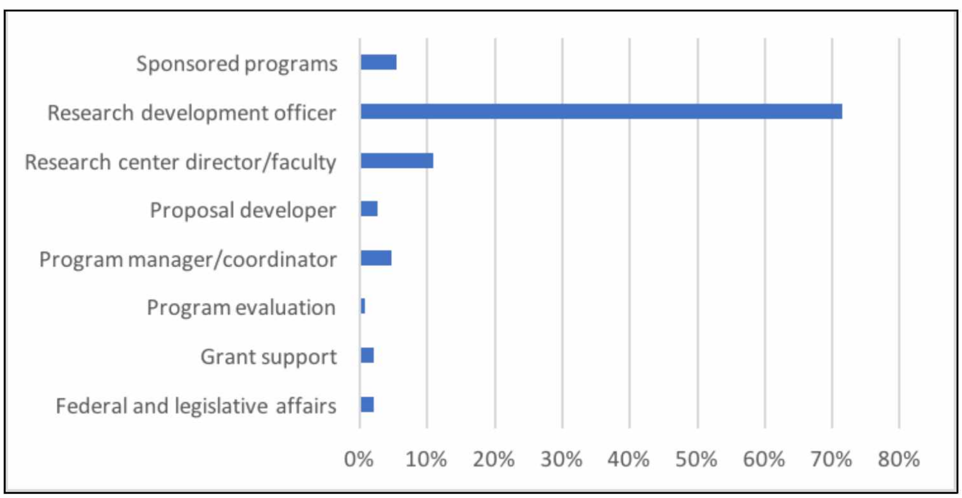

Figure 29. Plot of the number and type of job descriptions for the national position documents.

A summary of the EPSCoR position descriptions reflect the three main positions that are typically identified for leadership and management: project director, project administrator or associate project director and education, outreach and diversity manager (Figure 30). The eleven

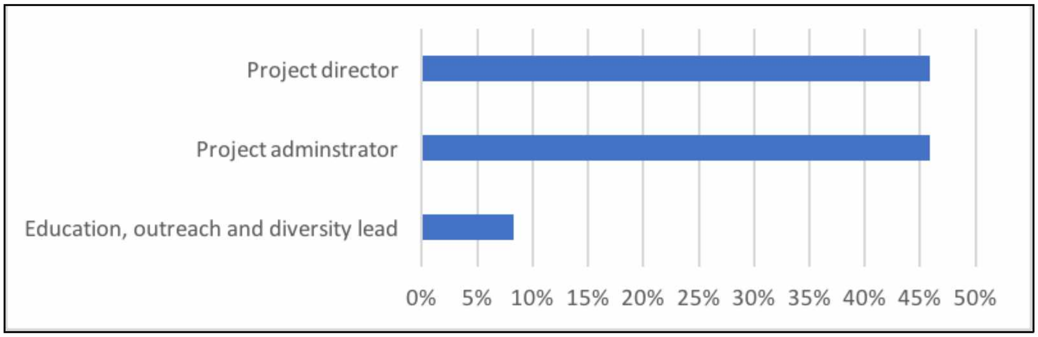

Figure 30. Plot of the number and type of job descriptions for the EPSCoR position documents.

concepts identified through group concept mapping served as the codes for the content analysis. The frequency of each code type for both national and EPSCoR documents is summarized in Figure 31. The relative frequency of each competence remained fairly similar between the two

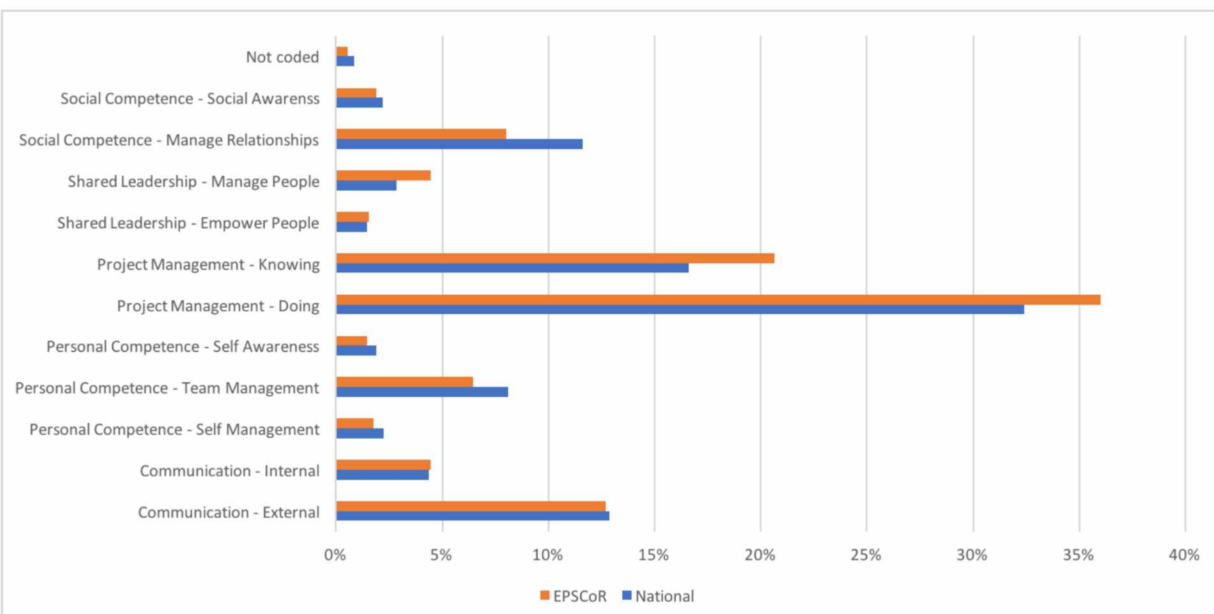

Figure 31. Percentage of quotes in each conceptual category.

sets of documents with project management - knowing and - doing representing a total of 49% of the national quotes and 57% of the EPSCoR quotes. Communication – external, personal competence – team management and social competence – manage relationships represented between 6% and 13% of all quotes, while the remaining codes accounted for less than 4% each. Close to 3,000 statements were analyzed and assigned at least one code. Examples of statements from each sub-category code are listed in Table 6 to give an idea of the types of statements that were encountered in the position descriptions.

The 11 sub-category titles developed in the group concept mapping analysis served as the codes for the content analysis. The coding and subsequent analysis of these statements helped to identify the competencies that institutions value in prospective employees whose positions are related to managing team science programs. While the vast majority of statements were assigned at least one and sometimes multiple codes, there were some that were not coded because they did not clearly match any of the concept group titles (Table 7).

Content analysis using ATLAS.ti allowed for an exploration into the most prevalent words found in the hiring documents. A summary of the top 50 words used in the national and EPSCoR documents is shown in Table 8. Of interest is that many words do refer to tangible and specific ideas found within the project management and communication conceptual groups (such as research, development, university, funding, faculty, EPSCoR, project, program, and NSF which are found in the top five words of each category). However, few words in either list refer to ideas associated with the concept groups of personal or social competence.

Table 6. Examples of statements from the document database for each code category

Code	Statement
Communication - External to Team	
	Represent the Office of Federal Relations at meetings, conferences, and events
	Serve as a senior representative of the University on strategic university-industry-government collaborations throughout the state
	Help researchers manage activities that involve multiple universities and outside partners
Communication - Internal to Team	
	Ability to understand the complex discourse related to cultural practices, collaboration, and research
	Manage and coordinate the proposal process, working with individuals at various levels in the organization to ensure successful integration
	Ability to work as part of a team and lead positive communication
Personal Competence - Manage Self	
	Integrity and high standards of excellence
	Must have the presence, interpersonal skills, and substance to win credibility within the team
	Good interpersonal skills and high degree of professionalism
Personal Competence - Manage Team	
	Managerial experience of large-proposal teams and team members
	Identifiable leadership skills in building consensus among groups of faculty and staff in the development of new research programs
	Manage team facilitation of large scale, competitive proposals in response to selected opportunities
Personal Competence - Self Awareness	
	Commitment to continually enhance one's own skill set in ways that will benefit the individual professionally and the trajectory of the project
	Requires independent judgment
	Ability to use discretion and maintain all confidentiality
Project Management - Doing	
	Formulate and execute strategies to accomplish those priorities
	Proven ability to balance needs of research community with compliance
	Funding opportunity identification and notification; demonstrated high-level administration and excellent organizational skills
Project Management - Knowing	
	Experience managing programs, special events and fundraising in higher education and nonprofits organizations
	The successful candidate will have a sophisticated understanding of the role and importance of sponsored research in a modern, entrepreneurial, university
	Proven ability to analyze and interpret financial and other data
Shared Leadership - Empower People	
	Personal and professional agility, the ability to make decisions, and the ability to drive and implement change
	Place confidence in colleagues
	Give proper credit to others
Shared Leadership - Manage People	
	Demonstrated supervisory skills with ability to catalyze positive change
	Manages the unit's staff
	Supervise and manage staff
Social Competence - Manage Relationships	
	Maintaining/strengthening relationships
	Demonstrated strong negotiation skills
	Foster relationships with potential industry and education partners
Social Competence - Social Awareness	
	Interacts professionally with all internal and external customers using strong interpersonal skills
	Good interpersonal skills and high degree of professionalism and social awareness
	Requires tact, diplomacy, and flexibility to work with faculty, executive administrators, staff, students, alumni, donors, and external stakeholders

Table 7. Example statements that did not fit into the existing code structure as defined by the group concept mapping concepts.

1	Ability to travel frequently in- and out-ot-state; requires a valid driver's license
2	Identify ways to strengthen pipelines for K-Post Doc linking our partner research universities together
3	Field work
4	Ability to travel to meetings within and outside the state
5	Perform other duties as assigned
6	Serve as the college's Research Integrity Officer
7	Maintain active research and teaching in the area of the applicant's expertise
8	Previsou teaching and research in a tenured faculty position at the rank of Associate or Full Professor
9	Ten or more years teaching, research and grant activities
10	More than $1 million in extramural funding
11	Ability to conduct internet research
12	Organize and facilitate technical short courses related to new initiative areas
13	A record of scholarly publications
14	Develop new curricula and degree programs in the brain science
15	Perform research and track activity in related areas of computational science and engineering
16	Demonstrated ability to perform research related to computational science

Integration of Results

The group concept map provided the codes for the content analysis of the position descriptions from the national database and the EPSCoR database. The ranking of code prevalence is almost identical between the national and EPSCoR data with only a slight difference in the rank of the two least common codes, personal competence – self-awareness and shared leadership – organizational empowerment (Table 9). In fact, 62% of the national statements and 70% of the EPSCoR statements coded were associated with project management – doing and knowing and communication – external.

Table 8. Word counts for the top 50 significant words in the National and EPSCoR PDs

	National PD	Count	EPSCoR PD	Count
1	research	2587	epscor	253
2	development	929	project	172
3	university	879	program	161
4	funding	680	research	157
5	faculty	671	nsf	126
6	experience	649	state	125
7	position	514	university	119
8	office	444	experience	112
9	proposal	439	position	111
10	skills	403	director	101
11	proposals	394	activities	89
12	work	385	administrative	83
13	grant	381	staff	82
14	director	380	work	81
15	ability	367	skills	79
16	support	354	programs	77
17	opportunities	346	education	76
18	federal	326	management	73
19	job	309	federal	72
20	campus	300	office	72
21	programs	300	job	71
22	science	292	duties	66
23	information	289	development	65
24	program	281	reports	59
25	new	276	ability	57
26	staff	276	administration	57
27	education	274	knowledge	57
28	degree	263	responsibilities	57
29	team	257	science	55
30	develop	240	working	55
31	writing	235	fiscal	54
32	related	233	team	54
33	management	230	meetings	50
34	academic	229	communication	48
35	strategic	227	day	48
36	knowledge	224	outreach	48
37	projects	217	projects	47
38	qualifications	212	level	46
39	working	212	reporting	46
40	president	210	time	45
41	state	210	annual	44
42	agencies	209	related	43
43	associate	205	national	42
44	center	204	requirements	42
45	sciences	203	budget	41
46	external	200	faculty	41
47	years	198	grant	41
48	demonstrated	190	new	39
49	provide	189	not	39
50	activities	181	data	37

Table 9. Rank order of codes (number and percentage) of national database and EPSCoR database. (Color codes are consistent with those from the concept map.)

CODES	NATIONAL (N,%)	EPSCoR (N,%)
Project Management - Doing	1183, 32	323, 36
Project Management - Knowing	607, 17	185, 21
Communication - External	471, 13	114, 13
Social Competence - Relationship Management	425, 12	72, 8
Personal Competence - Team Management	296, 8	58, 6
Communication - Internal	159, 4	40, 4
Shared Leadership - Organizational Management	104, 3	40, 4
Personal Competence - Self-management	82, 2	16, 2
Social Competence - Social Awareness	80, 2	17, 2
Personal Competence - Self-awareness	70, 2	13, 1
Shared Leadership - Organizational Empowerment	54, 1	14, 1

In order to compare the competencies deemed most important by current team science managers with those that are being highlighted through hiring practices, data from the group concept mapping and content analysis sections were integrated. By comparing the rank order of percentage of EPSCoR database sub-concepts with the importance ratings from the group concept mapping exercise (Table 10), differences between the two sets of information can be visualized. The EPSCoR position descriptions place the heaviest emphasis on project management – knowing and doing, communication – external and social competence – relationship management. However, the expert team science managers identified communication – internal, project management – doing, shared leadership – organizational management and communication – external as the top four most important sub-concepts for team science managers. Personal and social competencies are seen as relatively unimportant by the experts while shared leadership ranks higher with the team science managers than with those developing hiring documents.

Table 10. A comparison between A.) the percentage of sub-concepts from the coding frequency for the EPSCoR database and the B.) rank order ratings of importance from the group concept mapping exercise.

A.

CODES	EPSCoR (N)
Project Management - Doing	36
Project Management - Knowing	21
Communication - External	13
Social Competence - Relationship Management	8
Personal Competence - Team Management	6
Communication - Internal	4
Shared Leadership - Organizational Management	4
Personal Competence - Self-management	2
Social Competence - Social Awareness	2
Personal Competence - Self-awareness	1
Shared Leadership - Organizational Empowerment	1

B.

CONCEPT	IMPORTANCE
Communication - Internal	4.22
Project Management - Doing	4.18
Shared Leadership - Organizational Management	4.12
Communication - External	4.11
Project Management - Knowing	4.09
Social Competence - Social Awareness	4.02
Shared Leadership - Organizational Empowerment	4.00
Personal Competence - Self-management	3.94
Personal Competence - Self-awareness	3.94
Social Competence - Relationship Management	3.81
Personal Competence - Team Management	3.75

An analysis of the top five code frequencies associated with each job type within the national database resulted in Table 11. While the codes of communication – external, project management – know and doing, and social competence – relationship management, appear in each of the job classifications, personal competence – team management and shared leadership – organizational management rank in the top five of only some of the positions. Overall, the job descriptions result in similar code frequencies regardless of the specific position.

Table 11. Code document counts for national position documents. (Color codes are consistent with those from the concept map.) Yellow highlights show the five most prevalent code types in each position description category.

CODE	Fed/Leg Affairs	Grant Support	Program Mgr/Coor	Proposal Developer	Research Center	Research Developme	Sponsored Progams	Total
Project Management - Doing	14	36	107	15	98	842	66	1178
Project Management - Knowing	16	21	27	15	55	418	50	602
Shared Leadership - Organizational Empowerment	1	2	4	1	5	39	2	54
Shared Leadership - Organizational Management	4	1	12	0	16	66	4	103
Personal Competence - Self-management	2	2	4	4	11	56	3	82
Personal Competence - Team Management	1	11	13	6	23	224	18	296
Personal Competence - Self-awareness	1	0	2	2	11	50	4	70
Social Competence - Relationship Management	13	8	16	5	43	316	16	417
Social Competence - Social Awareness	2	1	2	4	16	48	7	80
Communication - External	21	15	28	8	38	338	23	471
Communication - Internal	3	7	9	3	20	111	6	159

An analysis of the EPSCoR documents shows a similar pattern (Table 12). Specifically, position descriptions for EOD leads, project administrators and project directors all focus predominantly on project management – knowing and doing, communication – external and shared leadership – relationship management. Position descriptions for EOD leads and project administrators placed more emphasis on personal competence – team management, while the project director's positions place more emphasis on communication – internal.

Table 12. Code document counts for EPSCoR position documents. (Color codes are consistent with those from the concept map.) Yellow highlights show the five most prevalent code types in each position description category.

CODE	EOD lead	Project Administrator	Project Director	Total
Project Management - Doing	14	177	132	323
Project Management - Knowing	14	90	81	185
Shared Leadership - Organizational Empowerment	0	7	7	14
Shared Leadership - Organizational Management	0	24	16	40
Personal Competence - Self-management	0	10	6	16
Personal Competence - Team Management	5	37	16	58
Personal Competence - Self-awareness	0	8	5	13
Social Competence - Relationship Management	3	32	37	72
Social Competence - Social Awareness	0	10	7	17
Communication - External	13	53	48	114
Communication - Internal	2	20	18	40

Chapter 5 Summary and Conclusion

Summary of Findings

Over the history of NSF EPSCoR which commenced in 1980, Project Directors and Administrators have been discussing management and leadership practices of these large, complex, statewide, capacity-building programs. These 37 years of collective experience have created a community of practice that includes team science managers from 28 states and territories who have been meeting multiple times each year to discuss tactics, share ideas, test strategies, identify skill sets and refine practices related to leading large, interdisciplinary team science projects. This study was an attempt to capture the comprehensive knowledge developed by this community of practice about the competencies required to manage large and complex science programs and the steps that the scientific community can take to increase the effectiveness of future efforts.

Project managers and leaders from the NSF EPSCoR community served as expert participants and, through a group concept mapping exercise, developed a map of the competency set required to effectively manage large and complex team science programs. While there is an existing body of knowledge that pertains to the general field of "project management" with associated professional organizations and degree programs, project management skills in and of themselves constituted only one of five major concepts that the experts identified as critical for a team science manager to master. Four other conceptual groupings were identified as important components of a competency framework and included: shared leadership, personal competence, social competence and communication. These five groups and their associated sub-categories constitute a competency framework and serve as a foundation for further work in this arena.

In summary, the first competence of project management was composed of “knowing” and “doing”. Statements in each of these categories reflected the reality that, like many large team science programs, EPSCoR is associated with state universities and must work within a large, bureaucratic, institutional setting. Competencies found in this cluster included understanding academic culture, developing complex budgets, understanding policies at a variety of levels from national to local, project tracking, process development and resource allocation.

Second, the concept of shared leadership, in which responsibility is broadly distributed, has been proposed as an effective strategy for large team science management projects. A recent meta-analysis found a positive relationship between shared leadership and team effectiveness (Wang et al., 2014). Shared leadership, as it is presented through the concept map, consisted of two components: organizational management and organizational empowerment. In this case, shared leadership was understood to be composed of organizational management, the process of organizing, planning, leading and controlling resources in order to advance the goals of the program; and organizational empowerment, the process of providing the tools, training, resources, encouragement and motivation that support team functioning. This general concept is seen to be adaptive as leaders and managers enable individuals to adopt new behavior and tools to further the goals of the program.

Third, the concept of personal competence was composed of three distinct ideas: team management, self-management, and self-awareness. Team management is the ability to coordinate a group of people to perform a task and included ideas such as creating a stable setting, believing in the mission of the team, instilling confidence in the team, recognizing excellence in team members, and serving as a mentor. Self-management and self-awareness have been previously identified as the two components of a personal competency framework for emotional intelligence (Goleman, 2005). Self-awareness is the ability of a leader to recognize her own emotions and their effect on herself and others. Statements that reflect this group's basic ideas included being open-minded, positive and optimistic, establishing trust, putting ego aside and showing respect to all team members. Self-management builds on self-awareness by incorporating self-control with the result that emotions are not the driver for management decisions regardless of the situation. Participants identified this concept in ideas such as the following: accept criticism and use the information to promote positive change, look at opportunities and solutions, exhibit a sense of calm and self-efficacy, identify strengths and weaknesses in yourself, and practice transparency in order to instill trust.

Fourth, the concept of social competence, which was first described by Goleman (2005) and part of his emotional intelligence skill set, refers to two ideas: relationship management and social awareness. Relationship management is defined as the bonds that a manager builds with others regardless of personal feelings and his ability to communicate clearly and handle conflicts in a productive manner. Statements that reflect this concept include: act as a liaison between numerous parties, act as an arbitrator, create a safe environment for people to share thoughts and ideas, help create a common language for team members, and know how to work with diverse populations. Social awareness is the ability to carefully consider other's needs and communicate in a manner that is productive for the situation. This competence builds on attributes such as empathy, organizational awareness and a service-centered approach to communication and is seen in the following statements: be a good active listener, be able to deal with difficult people, be calm, diplomatic and respectful, be sensitive to team dynamics, and identify talent and acknowledge the work of others.

Finally, communication is identified as the fifth core competence and further refined as that which takes place internally among team members and externally among the team and those outside. Communication is defined in this case as the imparting or exchange of information or news with “exchange” referring to the give and take of commonly constructed knowledge that includes multiple people. Statements in the “internal” group included the following: be able to articulate the benefits and costs of team science, be able to converse with many different kinds of collaborators and partners, be able to help the team connect the dots by seeing the big picture, and communicate a clear vision. Statements in the “external” sub-category included the following: possess the initiative to gain a broad understanding of the specific field of science, understand and be able to articulate the goals of the project in the larger context of broader impacts, understand the strategic mission and priorities of various stakeholders and oversight groups, and work with upper administration to get support and understanding. Interestingly, the need for verbal communication skills was included in the “internal” group while the need for written communication skills was included in the “external” sub-category, perhaps signifying the importance or relative degree of each type of communication with internal and externally focused communication exchanges.

This set of competencies reflects the complex nature of team science and the need for managers and leaders who are adept communicators, experienced project managers and have highly refined emotional intelligence skill sets. Understanding which competencies are most important and most feasible to expect in a team science manager can provide insight into how people structure future education programs and think about potential career tracks. Participants indicated that knowing how to effectively manage complex projects and communicate were of primary importance and highlighted two ideas from the concept of self-management that rated as highly important: be fair and consistent in decision making, and show respect to all. Of note, the ratings of feasibility also showed project management and communication skills at the top of the list with specific ideas that rated high on the feasibility scale scattered throughout the clusters of shared leadership, personal competence and social awareness.

Bringing these findings of feasibility and importance together in the go-zone plot allows for an examination of what the experts felt was together relatively feasible and important to require of a team science manager. Clusters 1, 2 and 5, project management, shared leadership and communication, displayed a higher proportion of go-zone statements than the other two clusters, indicating that participants found the statements in these groups both feasible and important. This could suggest that the skill sets in these clusters are an important place to focus efforts for future professional development programs for team science managers. Existing communities of practice within the NSF EPSCoR, NIH INBRE and STC organizations can advance the knowledge base and the practice of team science, and coordinated efforts to share information should continue to be a goal for the national science community. On the other hand, the fact that statements about social and personal competencies were not found as frequently in the go-zone might suggest that this would be a good place to focus efforts in curriculum development. In so doing, people may better understand that these are, in fact, learnable competencies and see the connection between them and other competencies such as communication, project management and shared leadership.

Clusters three and four that include the personal and social competencies are less prevalent in the go-zone, indicating that participants felt these statements were generally less important and less feasible. One reason for this pattern may be related to the traditional training that people in scientific fields typically receive through their educational programs. While it is not uncommon for scientists to receive some training in areas such as project management and communication and perhaps leadership, there are few programs that promote the development of personal and social competencies such as those identified in the group concept statements. Focused training, and therefore familiarity with these subjects, may provide the scientific community with important tool sets, increase the understanding of why they are important, and potentially lead to more effective team science outcomes.

The bridging analysis provides additional insight into how some of these ideas are related to each other. For instance, the statements with the highest bridging values, those that the experts grouped with a high number of other statements, were found primarily in the communication cluster. This indicates that communication skills were fairly ubiquitous and were related to many other aspects of team science management. Being a good and effective communicator will impact the ability of the manager to be successful in all arenas of his position. However, all of the lowest bridging, or anchor, values were located in cluster 3, personal competence. This highlights the fact that these statements strongly reflect the specific content in the local vicinity of that particular cluster and do not connect with a wide range of statements spread across the map. One reason for this may be related to the fact that science managers typically do not receive training to build these skill sets and see them as discrete yet important factors in their jobs. Experts recognize personal competencies as important to the overall effectiveness of the mission because they identified the statements and created the cluster. However, without formal training and focused professional development, people do not understand or actively forge the connections between these skills sets that includes team management, self-management and self-awareness and the overall goal of being an effective team science manager.

Key Competencies in Hiring Practices

The group concept mapping results were used as a lens to examine whether hiring practices across the country were considering the specific competencies identified through the group concept mapping. The results indicated that hiring committees within the EPSCoR programs are looking for people with connections to team science based on criteria that are similar to those being hired in non-EPSCoR positions. Both groups focus on fundamentals of project management and communication and may include some mention of team and relationship management. However, both groups miss the importance of the personal competence and shared leadership skills and do not highlight these competencies in their hiring documents.

These findings are supported by the word counts as well. The most prevalent 50 words from the EPSCoR and national databases (excluding words such as prepositions, articles and other non-descriptive words) suggest that project management and communication are the only important conceptual groups and do not acknowledge skills related to personal and social competencies such as empathy, self-awareness, social awareness, self-assessment, self-confidence, and more.

Finally, the differences identified in the demographic groups based on gender, longevity in team science management positions and role, show that individuals or even groups of people with similar demographic characteristics may not embrace or possess the entire suite of skills required to manage complex science programs. However, a diverse team that adopts a shared management approach could provide all of the requisite skills necessary and increase the chances of effective team science research. Identification of a management team at the beginning of a project should include conversations about who brings what types of skills and how large the team needs to be. Research has shown that the cost of creating large teams with significant diversity may be detrimental to the overall project effectiveness and that thinking strategically about the optimal team makeup is important (Cummings et al., 2013; Vermeulen, Parker, & Penders, 2010). Finally, time may be a significant factor in determining which teams have the most effective shared leadership. DeRue (2011) reported that mature multiteam systems display greater levels of shared leadership than less mature multiteam systems, presumably because shared leadership takes time to develop.

Future Research

This research provides a bridge between past and future work. Specifically, the foundation for a competency framework for team science managers has been established and can serve as an aid in creating career tracks, educational programs and professional development offerings for a better-defined field of team science management. Specific attention to developing curricula that address these competencies will be important as the field evolves. Further work is needed to refine the specifics of the framework and should rely on existing research, groups and organizations that connect ideas and people associated with team science management including the Science of Team Science, the National Organization of Research Development Professionals, the Society of Research (SRA), NSF EPSCoR, and NIH INBRE. The idea of future career opportunities that include positions such as a possible Interdisciplinary Executive Scientist (Hendren, 2014) have become part of the national conversation through groups such as Interdisciplinary Integration Research Careers Hub (Intereach) and others. Future challenges include thinking about spaces such as decision theaters and other collaborative work spaces that promote shared leadership, effective communication, and leadership training designed specifically for team science leaders. Finally, the continued dance between the translation among theoretical and practical advancements will be the ultimate measure of success.

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Appendix A. Institutional Review Board letter of exemption.

UNIVERSITY OF ALASKA FAIRBANKS

(907) 474-7800
(907) 474-5444 fax
uaf-irb@alaska.edu
www.uaf.edu/irb

Institutional Review Board

909 N Koyukuk Dr. Suite 212, P.O. Box 757270, Fairbanks, Alaska 99775-7270

February 16, 2015

To:	John Monahan, Ed.D. Principal Investigator
From:	University of Alaska Fairbanks IRB
Re:	[720257-1] PhD Dissertation: A framework of competency for interdisciplinary team science managers

Thank you for submitting the New Project referenced below. The submission was handled by Exempt Review. The Office of Research Integrity has determined that the proposed research qualifies for exemption from the requirements of 45 CFR 46. This exemption does not waive the researchers' responsibility to adhere to basic ethical principles for the responsible conduct of research and discipline specific professional standards.

Title:	PhD Dissertation: A framework of competency for interdisciplinary team science managers
Received:	February 13, 2015
Exemption Category:	2
Effective Date:	February 16, 2015

This action is included on the March 4, 2015 IRB Agenda.

Prior to making substantive changes to the scope of research, research tools, or personnel involved on the project, please contact the Office of Research Integrity to determine whether or not additional review is required. Additional review is not required for small editorial changes to improve the clarity or readability of the research tools or other documents.

Appendix B. Informed consent form.

Informed Consent Form

Developing a framework of competency for interdisciplinary team science managers

IRB 720257
Date Approved: Feb 16, 2015

Description of the Study
You are being asked to take part in a research study about team science management. The goal of this study is to identify what it takes to manage large interdisciplinary team science programs. You are being asked to take part in this study because you are familiar with managing these kinds of programs. Please read this form carefully. I encourage you to ask questions and take the opportunity to discuss the study before making a decision on whether or not to participate.

If you decide to take part, you will be asked to brainstorm ideas about what it takes to manage a successful team science program. This activity will take approximately one hour of your time. Subsequent activity will include rating and sorting the group's ideas. This will take an additional hour.

Risks and Benefits of Being in the Study
The potential benefit to you for taking part in this study is to contribute to improving the field of project management with the goal that future project managers will be better equipped to do their jobs and increase the effectiveness of the science team. There are no known risks to being a part of this study.

Confidentiality
Any information obtained about you from the research will be kept confidential.

Voluntary Nature of the Study
Your decision to take part in the study is voluntary. You are free to choose whether or not to take part in the study. If you decide to take part in the study you can stop at any time or change your mind and ask to be removed from the study. Participation in the project will require approximately two hours of time over the course of one month.

Contacts and Questions
If you have questions now, feel free to ask me now. If you have questions later, you may contact me (Pips Veazey) at 907.474.5989 or adveazey@alaska.edu.

The UAF Institutional Review Board (IRB) is a group that examines research projects involving people. This review is done to protect the people like you involved in the research. If you have questions or concerns about your rights as a research participant, you can contact the UAF Office of Research Integrity at 474-7800 (Fairbanks area) or toll-free 1-866-876-7800 (outside the Fairbanks area) or uaf-irb@alaska.edu.

……...

Statements of Consent

- I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I am 18 years old or older and have been provided a copy of this form. **YES** **NO** (circle one)
- I consent to being photographed for documentary purposes only. **YES** **NO** (circle one)

____
Signature of Participant Date

____
Signature of Person Obtaining Consent Date

Appendix C. Brainstorming template.

Team Science Management: Developing a Framework of Competency

Please review the statement below and generate brief phrases or sentences that complete this sentence from your point of view. Please spend a moment to think of issues of concerns that others might not think to include. If you have questions about the process, please contact Pips Veazey at 907.474.5989 or adveazey@alaska.edu.

"A specific thing that an effective team science manager needs to know or be able to do is … "

1	
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Thank you for your participation!

Please return this form to Pips Veazey

Appendix D. Group Concept Mapping statements.

Number	Statement
1	understand organizational behavior and address negative trends before they become permanent.
2	act as a cheerleader to praise, acknowledge and celebrate success
3	ensure the follow-up on tasks assigned during leadership meetings; serve as a taskmaster when required
4	make sure the team knows that you have their backs
5	have a clear understanding of project deliverables
6	convey that you genuinely believe in the mission of the team
7	be fair and consistent in decision making
8	do not micromanage
9	understand and be able to articulate the goals of the project in the larger context of broader impacts
10	inspire the team
11	coordinate reporting, writing and presentations
12	be flexible
13	supervise staff
14	understand sponsored programs pre and post award
15	articulate team outcomes and help team understand agency's definitions of outcomes
16	set aside time to get out of the office and connect with people face to face
17	know the institutional resources available to assist the team in the project
18	be able to deal with difficult people
19	instill confidence within team members and support people even if they have a different idea of how to accomplish programmatic goals
20	be patient and do not over-react
21	establish credibility within the team
22	have a good understanding of academic culture
23	put ego aside for the sake of the team
24	run effective meetings with specific purposes and outcomes
25	be sensitive to and aware of team dynamics
26	ensure good relationships with fiscal officers, deans, directors and administrators
27	understand how to develop complex budgets within an academic institution
28	know when to use carrots and sticks to keep everything on track; employ tact and display toughness when necessary
29	be able to influence decisions
30	know how to work with diverse populations of researchers and staff
31	have good negotiation skills
32	be good at troubleshooting
33	possess excellent verbal communication skills
34	work with upper administrators to get support and understanding
35	be able to manage complex competing demands and deadlines
36	be able to deal with change - be agile with shifting landscapes
37	connect people with potential opportunities, both people and activities
38	aspire to personal growth
39	establish regular and clear communications
40	admit mistakes, learn from them and move on
41	be detail-oriented
42	serve as a coach and promote team science ideas within the team
43	understand the strategic missions and priorities of the institution, state and federal government, and funding agency to frame the work of the team
44	display empathy when needed
45	create a safe environment for people to share thoughts and ideas
46	be the person who looks at opportunities and solutions, not problems and barriers
47	be persistent
48	understand federal, state and university policies and know where to get help and information
49	effective communication of expectations and products
50	help create a common language for team members
51	know the role and responsibilities of team members
52	know how to develop contingency plans
53	be calm, be diplomatic and be respectful
54	design and implement systems to standardize processes of the team
55	understand the tools availalbe for project planning and projection
56	be organized
57	be humble
58	be courageous
59	serve as a facilitator and understand how to facilitate meetings and events
60	establish authority

61	understand how to develop and implement strategic plans
62	understand how to hire and fire people
63	be open-minded
64	conserve resources, yet also be creative when opportunities come along that require resources (financial, human, otherwise)
65	be able to delegate
66	possess the initiative to gain a broad understanding of the specific field of science
67	have experience and confidence navigating a highly bureaucratic system
68	offer a balanced approach through the ability to prioritize
69	articulate the value of the program
70	be able to lead conflict resolution
71	possess excellent management skills
72	create an atmosphere of stability for the team
73	possess the ability and be empowered to make decisions
74	recognize excellence (especially in lower ranked positions)
75	focus on outcomes and impacts in order to continue to move the project work forward
76	serve as mediator among various people and groups when needed
77	possess good networking skills and arrange contacts for team members
78	look ahead 1 year at all times (and in some situations, even further)
79	understand creative budgeting and flexible management in order to attain goals of the program
80	leverage different sources of support
81	possess good writing skills
82	be a team player and be able to articulate the benefits and costs of team science
83	communicate a clear vision
84	be able to converse with many different kinds of collaborators and partners
85	understand the strengths and weaknesses of the team and how to use that as a strategic advantage
86	play to team member's strengths
87	act as an arbitrator in dealing with different people
88	be positive and optimistic
89	actively seek constructive criticism
90	lead and control the organizational efforts to produce the desired objectives and final outcomes
91	be able to communicate the team's science in a clear and concise manner to the public
92	have a sense of humor
93	be able to help the team connect the dots by seeing the big picture
94	create "buy in" by helping the team understand why and how the project can positively effect them
95	maintain an open door policy to team members for discussing issues that arise
96	know what you can control and what you can not
97	posess and promote good time management skills
98	be comfortable in a support role
99	be able to establish trust
100	be comfortable taking risks
101	communicate the budget in a clear, concise and transparent manner
102	know your own weaknesses and strengths
103	practice transparency in order to instill trust
104	understand program evaluation and work with evaluation team
105	be adept at personnel management
106	accept criticism and use the information to promote positive change
107	identify strengths and weaknesses in yourself as a leader
108	know the name and role of every person on the team and connect with each individual
109	develop systems to track team progress
110	show respect to all
111	empower people to do things and then let them do it
112	manage responsibilities without a lot of power
113	be a good active listener
114	serve as a mentor
115	see and understand the whole picture
116	do the homework and be prepared for every meeting and visit
117	take ownership of the position
118	act as a liaison between numerous parties depending on situation
119	exhibit a sense of calm and self-efficacy
120	identify talent and acknowledge the work of others

Appendix E. Similarity matrix.

Appendix F. Summary of statements and statistics.

Cluster	Point #	Point rating - Importance	Point rating - Feasibility	Point bridging	Statement
1A	**11**	4.22	4.22	0.34	coordinate reporting, writing and presentations
1A	**22**	4.17	4.39	0.50	have a good understanding of academic culture
1A	**67**	4.00	3.83	0.50	have experience and confidence navigating a highly bureaucratic system
1A	**17**	4.28	4.11	0.34	know the institutional resources available to assist the team in the project
1A	**80**	4.17	4.28	0.48	leverage different sources of support
1A	**79**	4.06	4.06	0.30	understand creative budgeting and flexible management in order to attain goals of the program
1A	**48**	4.28	4.22	0.46	understand federal, state and university policies and know where to get help and information
1A	**27**	4.11	4.11	0.45	understand how to develop complex budgets within an academic institution
1A	**104**	3.83	4.00	0.33	understand program evaluation and work with evaluation team
1A	**14**	3.83	4.00	0.32	understand sponsored programs pre and post award
1B	**35**	4.72	4.56	0.33	be able to manage complex competing demands and deadlines
1B	**64**	3.94	4.11	0.32	conserve resources, yet also be creative when opportunities come along that require resources (financial, human, otherwise)
1B	**54**	3.56	3.83	0.29	design and implement systems to standardize processes of the team
1B	**109**	4.06	4.33	0.27	develop systems to track team progress
1B	**116**	4.22	4.39	0.31	do the homework and be prepared for every meeting and visit
1B	**3**	4.50	4.67	0.47	ensure the follow-up on tasks assigned during leadership meetings; serve as a taskmaster when required
1B	**75**	4.44	4.44	0.31	focus on outcomes and impacts in order to continue to move the project work forward
1B	**5**	4.67	4.72	0.28	have a clear understanding of project deliverables
1B	**52**	3.94	4.28	0.27	know how to develop contingency plans
1B	**78**	3.94	4.17	0.38	look ahead 1 year at all times (and in some situations, even further)
1B	**24**	4.61	4.33	0.34	run effective meetings with specific purposes and outcomes
1B	**61**	3.89	4.17	0.25	understand how to develop and implement strategic plans
1B	**55**	3.78	4.28	0.27	understand the tools availalbe for project planning and projection
2A	**105**	3.89	4.06	0.33	be adept at personnel management
2A	**51**	4.39	4.61	0.30	know the role and responsibilities of team members
2A	**28**	3.94	4.06	0.33	know when to use carrots and sticks to keep everything on track; employ tact and display toughness when necessary
2A	**90**	3.89	3.83	0.35	lead and control the organizational efforts to produce the desired objectives and final outcomes
2A	**68**	4.11	4.28	0.38	offer a balanced approach through the ability to prioritize
2A	**97**	4.33	4.56	0.46	posess and promote good time management skills
2A	**71**	4.28	4.33	0.42	possess excellent management skills
2A	**115**	4.33	4.50	0.42	see and understand the whole picture
2A	**13**	3.83	4.11	0.34	supervise staff
2A	**1**	4.17	3.94	0.34	understand organizational behavior and address negative trends before they become permanent.
2A	**85**	4.17	4.17	0.34	understand the strengths and weaknesses of the team and how to use that as a strategic advantage
2B	**36**	4.39	4.00	0.59	be able to deal with change - be agile with shifting landscapes
2B	**65**	4.17	4.33	0.30	be able to delegate
2B	**98**	3.56	4.39	0.61	be comfortable in a support role
2B	**41**	4.22	4.17	0.73	be detail-oriented
2B	**32**	4.11	4.17	0.71	be good at troubleshooting
2B	**56**	4.28	4.50	0.78	be organized
2B	**47**	3.94	4.50	0.56	be persistent
2B	**8**	3.67	3.94	0.32	do not micromanage
2B	**96**	3.94	4.17	0.44	know what you can control and what you can not
2B	**112**	3.61	3.61	0.45	manage responsibilities without a lot of power
2B	**86**	4.11	4.00	0.28	play to team member's strengths
2B	**73**	3.89	3.78	0.55	possess the ability and be empowered to make decisions
2B	**117**	4.17	4.61	0.56	take ownership of the position
3A	**29**	3.72	3.56	0.38	be able to influence decisions
3A	**6**	3.94	4.11	0.23	convey that you genuinely believe in the mission of the team
3A	**72**	3.67	3.61	0.19	create an atmosphere of stability for the team
3A	**19**	3.94	3.44	0.11	instill confidence within team members and support people even if they have a different idea of how to accomplish programmatic goals
3A	**108**	3.78	3.89	0.29	know the name and role of every person on the team and connect with each individual
3A	**74**	3.89	4.61	0.11	recognize excellence (especially in lower ranked positions)
3A	**114**	3.28	4.06	0.16	serve as a mentor
3B	**106**	4.11	4.28	0.18	accept criticism and use the information to promote positive change
3B	**38**	3.50	3.89	0.18	aspire to personal growth
3B	**100**	3.33	3.89	0.33	be comfortable taking risks
3B	**58**	3.44	4.06	0.11	be courageous
3B	**7**	4.44	4.22	0.13	be fair and consistent in decision making
3B	**12**	3.94	4.06	0.10	be flexible
3B	**46**	4.17	4.44	0.34	be the person who looks at opportunities and solutions, not problems and barriers
3B	**111**	4.33	4.17	0.16	empower people to do things and then let them do it
3B	**60**	3.67	3.83	0.30	establish authority
3B	**21**	4.22	3.78	0.08	establish credibility within the team
3B	**119**	3.83	4.22	0.08	exhibit a sense of calm and self-efficacy
3B	**107**	4.11	4.28	0.25	identify strengths and weaknesses in yourself as a leader
3B	**102**	3.89	4.39	0.23	know your own weaknesses and strengths
3B	**4**	3.89	3.83	0.23	make sure the team knows that you have their backs
3B	**103**	4.22	4.17	0.09	practice transparency in order to instill trust
3C	**89**	3.61	4.22	0.14	actively seek constructive criticism
3C	**40**	4.17	4.44	0.06	admit mistakes, learn from them and move on
3C	**99**	4.00	3.83	0.00	be able to establish trust
3C	**57**	3.50	4.17	0.08	be humble
3C	**63**	4.28	4.33	0.06	be open-minded
3C	**88**	3.83	4.33	0.12	be positive and optimistic
3C	**44**	3.89	4.17	0.24	display empathy when needed
3C	**92**	3.56	4.22	0.17	have a sense of humor
3C	**10**	3.72	3.61	0.14	inspire the team
3C	**23**	4.22	4.17	0.05	put ego aside for the sake of the team
3C	**110**	4.61	4.67	0.02	show respect to all

Cluster	Point #	Point rating - Importance	Point rating - Feasibility	Point bridging	Statement
4A	**118**	3.72	4.06	0.64	act as a liaison between numerous parties depending on situation
4A	**87**	3.44	3.94	0.84	act as an arbitrator in dealing with different people
4A	**70**	3.78	3.67	0.55	be able to lead conflict resolution
4A	**94**	4.17	3.78	0.56	create "buy in" by helping the team understand why and how the project can positively effect them
4A	**45**	4.06	4.28	0.78	create a safe environment for people to share thoughts and ideas
4A	**31**	3.89	4.11	0.63	have good negotiation skills
4A	**50**	3.83	3.72	0.50	help create a common language for team members
4A	**30**	4.33	4.06	0.62	know how to work with diverse populations of researchers and staff
4A	**76**	3.72	3.83	0.66	serve as mediator among various people and groups when needed
4A	**16**	3.61	3.50	0.63	set aside time to get out of the office and connect with people face to face
4A	**62**	3.39	4.11	0.56	understand how to hire and fire people
4B	**2**	3.67	4.61	0.54	act as a cheerleader to praise, acknowledge and celebrate success
4B	**113**	4.28	4.56	0.50	be a good active listener
4B	**18**	4.00	3.33	0.36	be able to deal with difficult people
4B	**53**	4.22	4.67	0.37	be calm, be diplomatic and be respectful
4B	**20**	4.11	3.89	0.43	be patient and do not over-react
4B	**25**	4.39	4.00	0.31	be sensitive to and aware of team dynamics
4B	**120**	4.17	4.39	0.29	identify talent and acknowledge the work of others
4B	**95**	3.83	4.39	0.47	maintain an open door policy to team members for discussing issues that arise
4B	**42**	3.56	3.89	0.47	serve as a coach and promote team science ideas within the team
5A	**69**	4.17	4.17	0.87	articulate the value of the program
5A	**82**	4.06	4.22	0.69	be a team player and be able to articulate the benefits and costs of team science
5A	**91**	4.22	4.22	0.75	be able to communicate the team's science in a clear and concise manner to the public
5A	**84**	4.39	4.39	0.86	be able to converse with many different kinds of collaborators and partners
5A	**93**	4.17	4.00	1.00	be able to help the team connect the dots by seeing the big picture
5A	**83**	4.22	4.28	0.72	communicate a clear vision
5A	**26**	4.33	4.00	0.79	ensure good relationships with fiscal officers, deans, directors and administrators
5A	**33**	4.50	4.44	0.78	possess excellent verbal communication skills
5A	**77**	3.89	4.28	0.82	possess good networking skills and arrange contacts for team members
5B	**15**	4.33	4.06	0.71	articulate team outcomes and help team understand agency's definitions of outcomes
5B	**101**	4.00	4.44	0.73	communicate the budget in a clear, concise and transparent manner
5B	**37**	3.78	4.17	0.93	connect people with potential opportunities, both people and activities
5B	**49**	4.28	4.33	0.63	effective communication of expectations and products
5B	**39**	4.50	4.44	0.67	establish regular and clear communications
5B	**81**	4.44	4.39	0.77	possess good writing skills
5B	**66**	3.50	3.94	0.72	possess the initiative to gain a broad understanding of the specific field of science
5B	**59**	3.94	4.06	0.67	serve as a facilitator and understand how to facilitate meetings and events
5B	**9**	4.06	4.11	0.65	understand and be able to articulate the goals of the project in the larger context of broader impacts
5B	**43**	4.28	4.22	0.70	understand the strategic missions and priorities of the institution, state and federal government, and funding agency to frame the work of the team
5B	**34**	4.06	3.94	0.68	work with upper administrators to get support and understanding